OPEN-PIT COPPER MINING METHODS, MORENCI BRANCH, PHELPS DODGE CORP., GREENLEE COUNTY, ARIZ.

By W. R. Hardwick

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Information Circular 7911

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OPEN-PIT COPPER MINING METHODS, MORENCI BRANCH, PHELPS DODGE CORP., GREENLEE COUNTY, ARIZ.[1]

by

W. R. Hardwick[2]

SUMMARY AND INTRODUCTION

This paper describes mining methods and practices of the Morenci Branch, Phelps Dodge Corp., Greenlee County, Ariz. It is one of a series being prepared by the Bureau of Mines on mining methods, practices, and costs in various mining districts in the United States. A similar program, conducted from 1928 to 1939, was generally conceded to have contributed substantially to improving the efficiency of mining operations.

The morenci open-pit mine (see photograph, fig. 1) is in southeastern Arizona (fig. 2), on U.S. Highway 666 about 5 miles north of Clifton, county seat of Greenlee County. The concentrator and smelter are near the mine at an altitude of about 4,400 feet. Figure 3 is a map of the mine and plant.

Copper ore is mined, concentrated, and smelted, as shown in the product flowsheet, figure 4. Copper is cast in anodes, each weighing approximately 700 pounds, and sent to the Phelps Dodge refinery in El Paso, Tex. Molybdenum is recovered as a byproduct.

This report gives a brief history of the district; describes the ore deposit; outlines methods of prospecting, exploration, sampling, and ore estimation; and explains development and mining operations, including drilling and blasting, loading, ore and waste transportation, auxiliary operations, waste leaching, engineering control, and operating control. Ore extraction, production rates, safety measures, fire protection, mine drainage, and organization are described briefly. Concentrating and smelting operations are outlined. Field work for this report was done late in 1956.

ACKNOWLEDGMENT

Acknowledgment is made to the executives and staff of Phelps Dodge Corp. for permission to publish this paper. Special acknowledgment is due Lyle M. Barker, manager, and Warren E. Fenzi, general superintendent, Morenci Branch, Phelps Dodge Corp. Manufacturers have been generous in supplying specifications for equipment.

1/ Work on manuscript completed August 1957.

2/ Mining engineer, Bureau of Mines, Region III, Tucson, Ariz.

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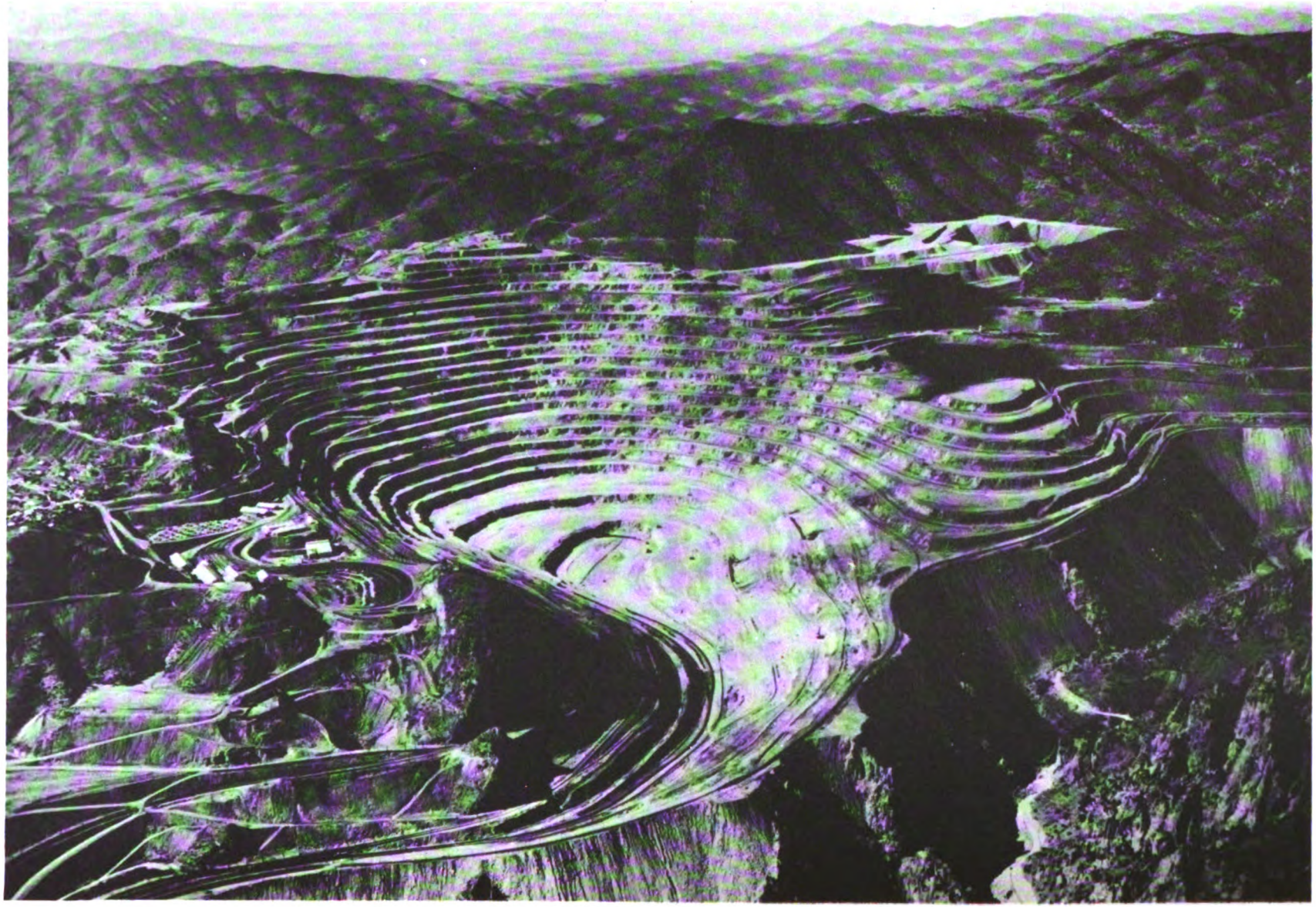

FIGURE 1. - Morenci Open-Pit Mine. *(Courtesy Phelps Dodge Corp.)*

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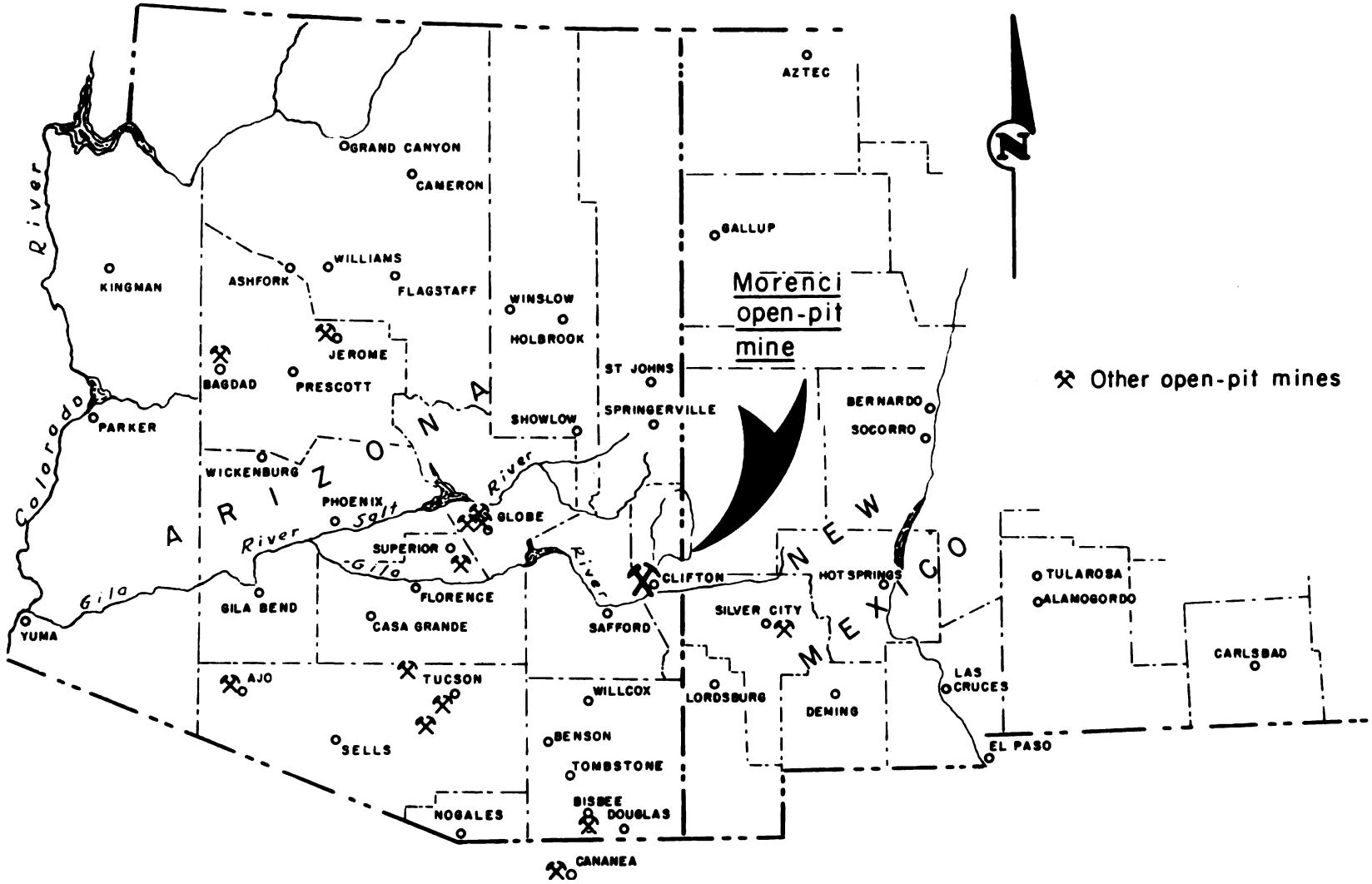

FIGURE 2. - Location of Morenci Open-Pit Mine.

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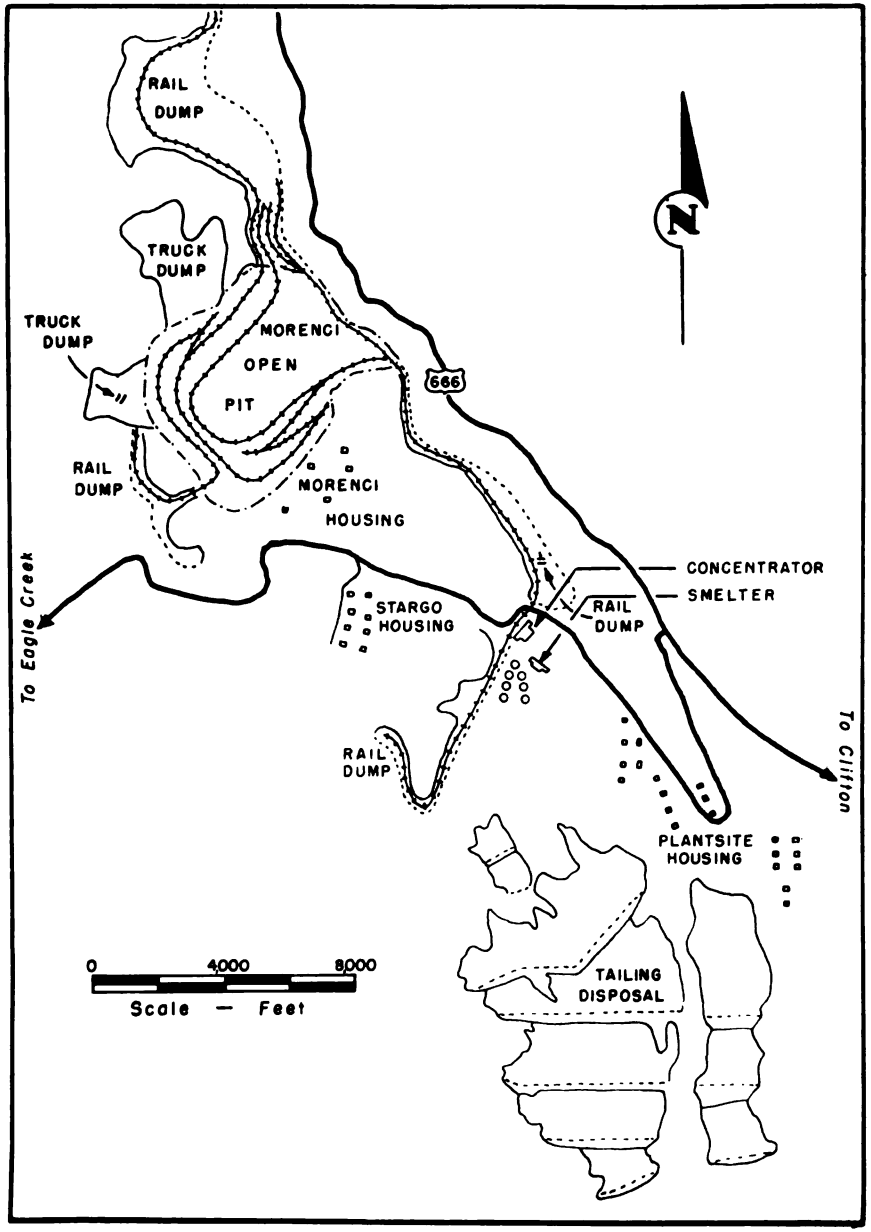

FIGURE 3. - Map, Open-Pit Mine and Plant, Morenci, Ariz.

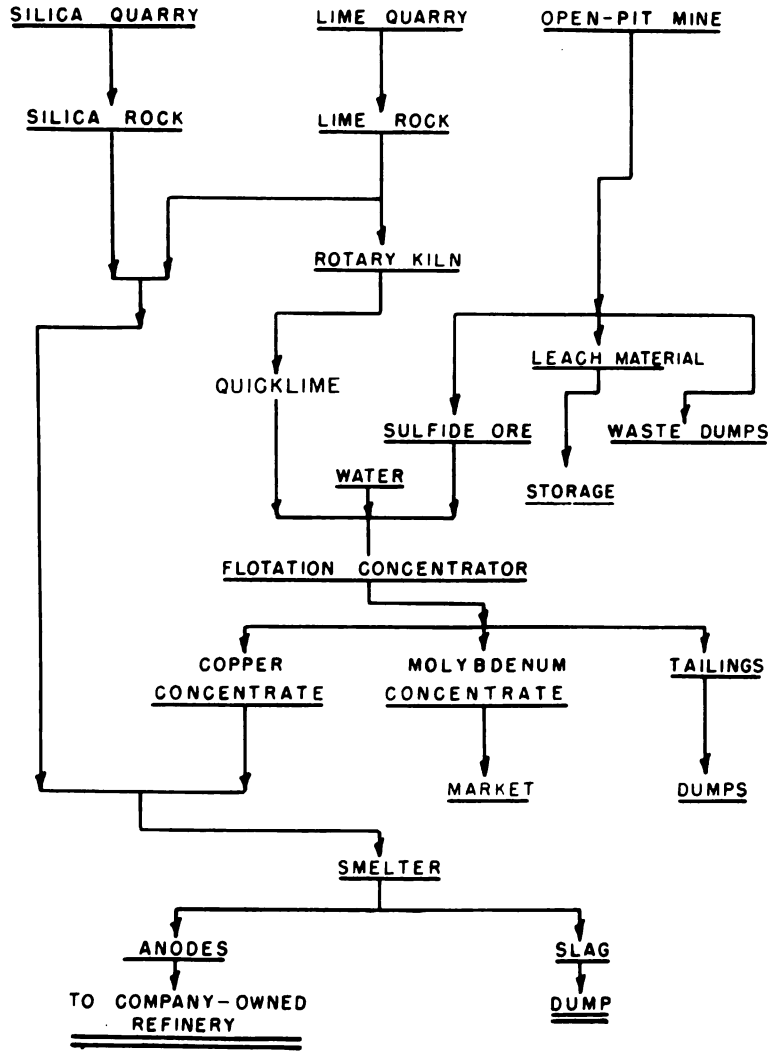

FIGURE 4. - Flowsheet, Morenci Branch, Phelps Dodge Corp., Greenlee County, Ariz.

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The author obtained help from papers describing former underground operation of Phelps Dodge Corp. at Morenci.[3] [4] Published articles on the Morenci mine, listed as footnotes to the report, were consulted. Maps and drawings were made available by Phelps Dodge Corp. The author also consulted several papers, presented at meetings of the American Mining Congress and the American Institute of Mining, Metallurgical & Petroleum Engineers but not yet published. Information from these papers was used freely, and valuable information was gathered from lengthy discussions with members of the operating and engineering staff.

HISTORY OF DEPOSIT

The Morenci mine is in T. 4 S., R. 29 E., Gila and Salt River meridian, along the west side of Chase Creek, a tributary that enters the San Francisco River a few miles above its confluence with the Gila River in eastern Arizona. The bottom bench of the open-pit mine has an altitude of 4,350 feet and the top bench of 5,650 feet. The mean temperature ranges from a maximum of 80.1° F. to a minimum of 53.1° F. The average annual precipitation is 13.2 inches.[5] Permanent streams flow in Eagle Creek and the San Francisco River. The nearby town of Clifton is serviced by a branch of the Southern Pacific Railroad that joins the main line at Lordsburg, N. Mex. Freight is hauled from Clifton to the mine by a company-owned industrial railroad.

The rich carbonate copper ore near Copper Mountain was discovered by Americans in 1864 when Henry Clifton and a group of prospectors from Silver City, N. Mex., visited the area. The first mining claims were located in 1872 by Isaac Stevens and Bob Metcalf, prospectors who also founded the town of Clifton.[6]

Longfellow Copper Co. was organized in 1873 and Detroit Copper Co. in 1874. Phelps Dodge Corp. acquired a half interest in Detroit Copper Co. in 1882. The Longfellow group, including the Humboldt and Morenci mines, was acquired by Arizona Copper Co., Ltd., in 1883. In 1917 Detroit Copper Co. became the Morenci Branch of the Phelps Dodge Corp. In 1922 Arizona Copper Co. (including Shannon Copper Co., which it had acquired in 1921) was united with Phelps Dodge Corp. The Longfellow, Shannon, Detroit, Coronado, and Arizona Copper companies owned all of the important claims. Thus, all of the major mining properties of the Morenci district were consolidated under the management of Phelps Dodge Corp. These companies had produced more than 1,500,000,000 pounds of copper before they were consolidated.

3/ Mosier, McHenry, and Sherman, Gerald, Mining Practice at Morenci Branch, Phelps Dodge Corp., Morenci, Ariz.: Bureau of Mines Inf. Circ. 6107, March 1929, 34 pp.

4/ Mining Congress Journal, Papers on Operating Problems, Morenci Branch, Phelps Dodge Corp.: April 1929, 24 pp.

5/ Smith, H. V., The Climate of Arizona: Univ. Arizona, Tucson, Agricultural Exp. Sta. Bull. 197, July 1945, p. 87.

6/ Tuck, Frank J., History of Mining in Arizona: Arizona Dept. Mineral Resources, Phoenix, Ariz., July 1955, pp. 27-33.

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Important economies resulted from the consolidation. Continuous ore bodies could be mined as a unit. A single concentrating plant and smelting plant was operated, and overhead and operating costs were reduced by eliminating duplication. The Morenci Branch, Phelps Dodge Corp., continued to operate the Humboldt mine and produced 456,000,000 pounds of copper from 1922 to 1932, when the mine was closed because of the low price of copper.

Many mining methods have been used in the district. These include open-cut, surface and underground glory-hole, open-stope, cut-and-fill, shrinkage, overhand and underhand square-set, and top-slicing methods. From 1922 to 1926, a method known as the Morenci timber-slide caving system, was developed and used.7/ From 1922 to 1932, much of the ore was mined by this method, and caving was the only method in use when the mine was closed in 1932.

The first smelters in the district treated high-grade copper oxide ores from veins near the surface. Later, rich chalcocite ore was discovered and mined. After the readily available high-grade ore was depleted, production consisted of relatively low-grade ore that was mined by caving, then concentrated.

By 1937, plans to mine the low-grade ore body by an open-pit method were completed. Conditions were favorable, and the operation was started. Operation of a new concentrating plant with a daily capacity of 25,000 tons was begun in January 1942, after 49,183,602 tons of overburden had been stripped.8/

After World War II had started, Phelps Dodge Corp., cooperating with the Defense Plant Corporation, increased the daily capacity of the mine and concentrator to 45,000 tons. This expansion was completed in 1943, and 40,756,353 tons of ore and waste was mined that year.9/ Expansion of the smelter was completed in January 1944.

Production from lode mines in the Clifton-Morenci district from 1873 through 1934 totaled 1,982,300,000 pounds of copper.10/ The cumulative production from the open pit at the end of September 1956 was 205,000,000 tons of ore and 420,000,000 tons of waste. At that time daily production averaged 52,000 tons of ore and 88,000 tons of waste by rail and 30,000 tons of waste by truck haulage.

7/ Work cited in footnote 3, p. 5.

8/ Much of the information on the history of Morenci has been taken from Minerals Yearbook, published annually by the Bureau of Mines.

9/ Woodward, G. E., and Luff, Paul, Gold, Silver, Copper, Lead, and Zinc in Arizona: Bureau of Mines Minerals Yearbook, 1943, p. 255.

10/ Elsing, Morris J., and Heineman, E. S., Arizona Metal Production: Arizona Bureau of Mines Bull. 140, Tucson, Ariz., 1936, p. 49.

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DESCRIPTION OF DEPOSIT[11-13/]

The oldest rocks of the Morenci district are Precambrian granite and schist. About 1,000 feet of Paleozoic beds rests unconformably on this base and is unconformably overlain by Cretaceous beds. (See fig. 5.) Several granite and monzonite porphyry rocks invaded these beds, probably in early Tertiary time. Lindgren states: "The porphyries form an almost continuous series of light-grey acidic or predominatingly feldspathic rocks, ranging from diorite-porphyry through monzonite-porphyry to granite-porphyry."[14/] Two types of granite porphyry and one monzonite porphyry are shown in the area covered by the Morenci open-pit mine (fig. 6).

A protore containing pyrite, chalcopyrite, and sphalerite was formed, probably as a later phase of the porphyry invasion. A period of erosion followed, during which the present ore bodies were formed by oxidation and enrichment of the protore. Probably in late Tertiary time, eruptions of lava covered the district. Part of these lavas now have been removed by erosion.

Three types of ore bodies occur in the Morenci district: (1) Irregular or roughly tabular contact-metamorphic bodies in limestone or shale near porphyry, (2) lodes or veins in fault zones, and (3) irregular deposits of low-grade disseminated ore in porphyry. The low-grade ore body now being mined by the open-pit method is the last type.

The disseminated ore body is in medium-hard porphyry. The principal sulfide minerals are chalcocite and pyrite.[15/] Chalcopyrite and bornite have been identified, and small quantities of covelite are present. The chalcocite occurs as a coating on pyrite and as a dissemination in the gangue.

The topography near the ore body is extremely rough. Chase Creek cuts through the overlying rocks to the porphyry, exposing the ore-bearing formations. The ore extends westward into the high ridge that trends southward from Coronado Mountain and terminates in Copper Mountain. The altitude of this ridge is 6,370 feet just northwest of the mine, and the altitude of the bottom of Chase Creek is about 4,250 feet opposite the open pit.

The average thickness of the capping was 216 feet and the maximum thickness about 500 feet. The ore extends through a vertical range of about 1,300 feet. The surface outline of the ore body forms a rough oval and covers an area of approximately 700 acres. Some oxidized copper minerals are present

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11/ Lindgren, Waldemar, The Copper Deposits of the Clifton-Morenci District, Arizona: Geol. Survey Prof. Paper 43, 1905, 375 pp.

12/ Butler, B. S., and Wilson, Eldred D., Some Arizona Ore Deposits: Arizona Bureau of Mines Bull. 145, Tucson, Ariz., 1938, pp. 72-80.

13/ Lindgren, Waldemar, Description of the Clifton Quadrangle: Geol. Survey Atlas of the United States, Clifton Folio, Arizona, 1905, 13 pp.

14/ Work cited in footnote 11, p. 78. Note. - P. 78 is the page in the Lindgren paper cited.

15/ Cody, B. H., Milling Practices at Concentrator of Morenci Reduction Works: Min. Technol., AIME, vol. 11, No. 4, July 1947, 26 pp.

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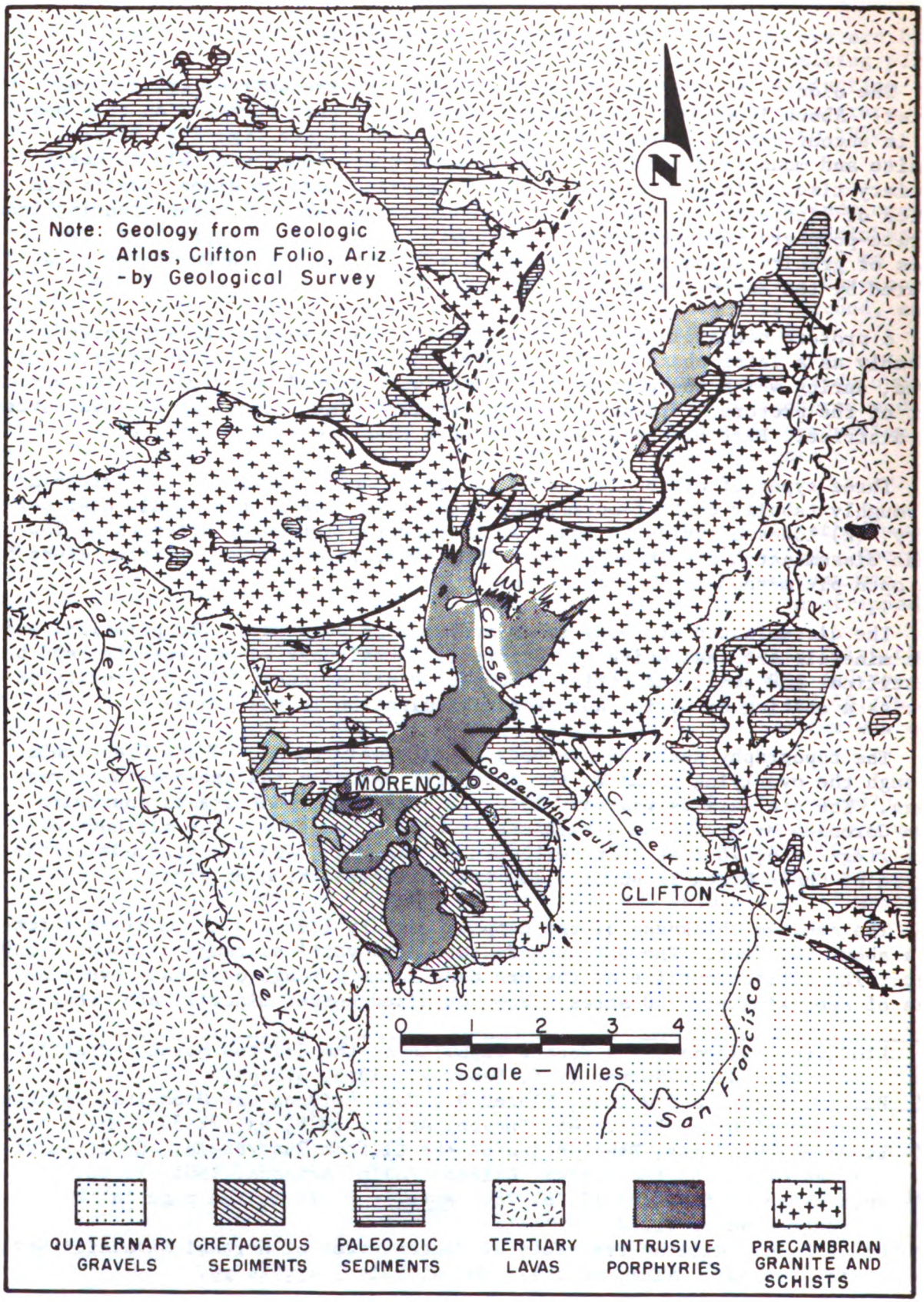

FIGURE 5. - Geologic Map of Morenci Area, Showing Major Faults.

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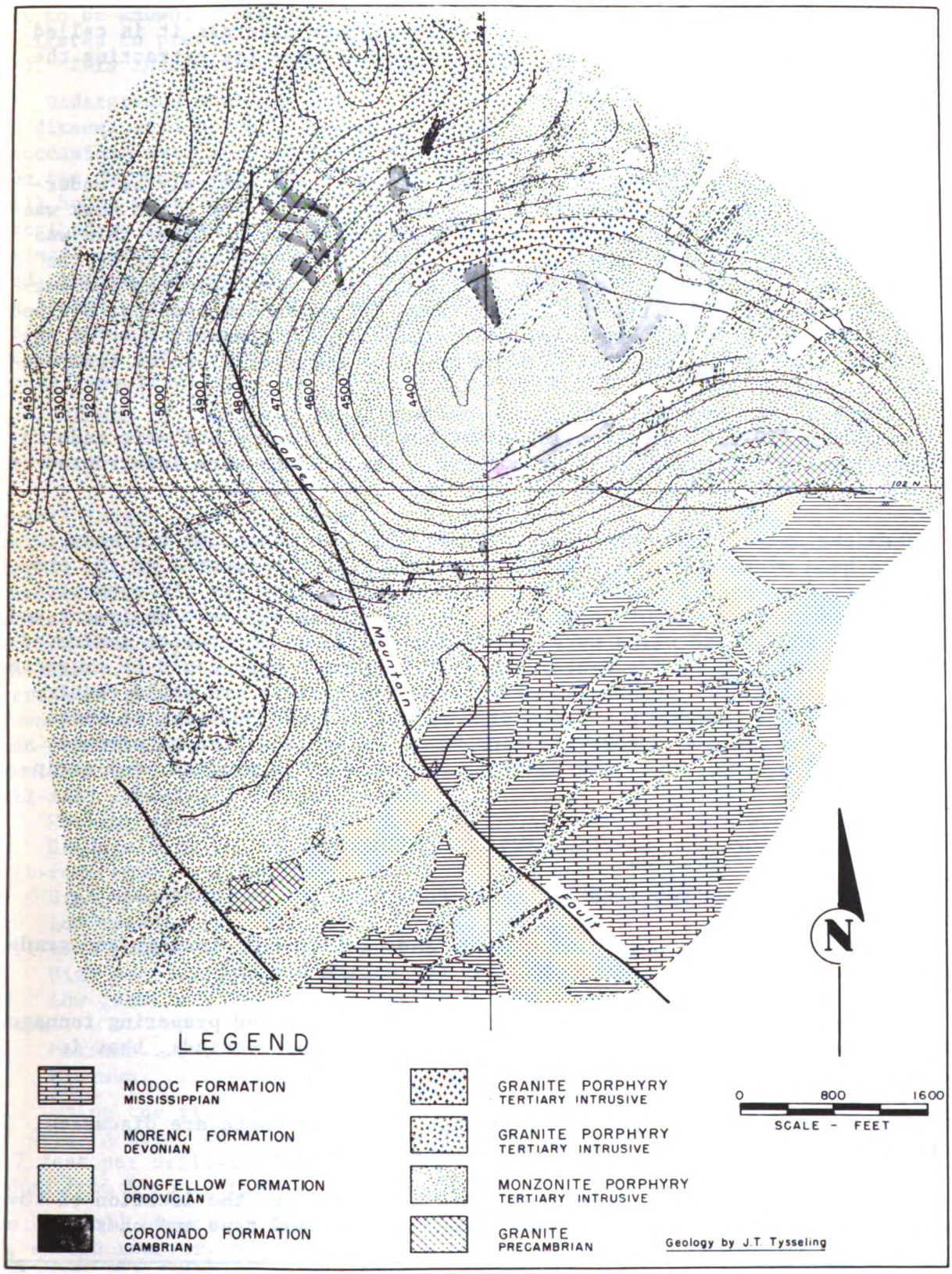

FIGURE 6. - Geologic Map of Morenci Open Pit. *(Courtesy Phelps Dodge Corp.)*

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in part of the capping. When capping contains copper minerals it is called leach material and is dumped where provision can be made for extracting the copper content at some future time.

PROSPECTING AND EXPLORATION

The large, low-grade Humboldt ore body was explored entirely by underground drifts, raises, and underground diamond drilling. The first work was the promiscuous search for high-grade ore from the surface. Later this was supplemented by systematic work to provide grade, size, and outline of the ore body. Early exploration was done in the open-pit ore body from the surface. Some underground drifts and riases were driven in the open-pit ore body from the Humboldt workings and other underground mines; however, most of the exploration was done by vertical diamond-drill or churn-drill holes from the surface.

In 1930 a 150-ton-per-day pilot plant was built, and plans were made to bring the open-pit ore body into production. These plans were interrupted by the drop in demand for copper and the depression of 1930-34.

When the underground mine was closed in 1932, the Humboldt ore body, which had been mined for more than 40 years, was almost exhausted at the ore-grade cutoff then prevailing. During the shutdown, plans for the open pit were improved to take advantage of new developments in open-pit equipment and methods. By 1937 these plans were completed. Engineering studies indicated that 230,000,000 tons of ore containing 1.06 percent copper could be extracted by open-pit mining.16/ It was estimated that mining this ore would require the removal of 239,000,000 tons of waste and that 43,000,000 tons of waste would have to be removed before the mine would be in condition to produce 25,000 tons of ore per day. The decision was reached to proceed, and stripping was begun.

SAMPLING AND ORE ESTIMATION

Sampling has been required at the Morenci mine for two reasons:

1. Preparing long-range mining plans and estimates of tonnage and grade involving large blocks of the ore body or the entire ore body.

2. Separating ore from waste during actual mining and preparing tonnage and grade estimates for relatively small areas and short periods, that is, estimates of ore and waste to be mined month by month.

Sampling and calculations for separating ore from waste are discussed later under engineering control of the mining operation.

Before development was started it was essential for the location of the ore body, thickness of the overburden, grade of ore, and type and character of

16/ Lawson, Walter C., Preliminary Stripping of the Morenci Open Pit, Arizona: Min. Technol., AIME, vol. 2, No. 5, September 1938, 15 pp.

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rock to be known. Furthermore, areas to be covered with waste had to be investigated to preclude the possibility that concealed ore bodies would be covered. This information was obtained by sampling.

Underground openings, such as accessible drifts and raises in the area of the disseminated ore body, were sampled with hammer and moil. Areas that were inaccessible were sampled by vertical diamond-drill holes from underground and from the surface. Before 1929, thousands of feet of churn-drill and diamond-drill holes were drilled and sampled. Early diamond-drill sampling has been described by Mosier and Sherman.17/ In the present drilling program at Morenci, churn drills are used for the most part. Drills of two sizes are used; the heavier drill is preferred, but the terrain is extremely rugged and the lighter drill is more mobile. Four drills of each size are used. All drills are equipped with semitrailer mountings on a single axle. The wheels are removed during operation, and guy ropes are used to improve stability. General specifications for the drills are compared in table 1.

TABLE 1. - General specifications of churn drills used at Morenci

	Light drill	Heavy drill
Overall length - derrick down.....feet	32-3/4	34
Overall width - derrick down.....do.	8	8-1/3
Overall height - derrick down.....do.	10-1/2	11-5/6
Overall weight.....pounds	22,975	33,000
Derrick capacity - 2-line, single-block.....do.	30,000	35,000
Derrick capacity - 6-line, triple-block and A-frame.....do.	75,000	120,000
Derrick height.....feet	54	54
Crown-sheave diameter.....inches	25-5/8	30
Sand-sheave diameter.....do.	20	25
Beam sheave.....do.	21-1/4	26
Bull-reel capacity - 7/8-inch line:		
Working side.....feet	1,770	3,570
Storage side.....do.	2,040	3,570
Bull-reel speed - 1 layer:		
High speed.....feet per minute	210	230
Low speed.....do.	110	123
Bull-reel pull - 1 layer:		
High gear.....pounds	9,800	17,400
Low gear.....do.	18,750	32,500
Stroke:		
Maximum.....inches	42	46
Minimum.....do.	24	20

During the first 9 months of 1956, drills were operated two 8-hour shifts per day. A total of 30,645 feet was drilled in 2,854 shifts - approximately 10.7 feet per drill-shift. The holes averaged about 1,000 feet in depth and ranged from 6 to 12 inches in diameter.

A small amount of diamond-drill work is contracted. A provision requiring a core recovery of 90 percent is included in the contract. NX bits are used, and the drill is operated one shift per day. Only the core is used for samples; the sludge is not saved. The present operator has averaged 30.5 feet per shift with a core recovery of 94 percent.

17/ Work cited in footnote 3, p. 5.

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A special splitter (fig. 7) has been designed at Morenci to split the churn-drill cuttings. Figure 8 shows the splitter in use. The sample interval is 10 feet in ore and 25 feet in a known waste area. Cuttings from a 10-foot sample in the 12-inch churn-drill hole weigh over 1,200 pounds. The splitter separates one-eighth of this amount, or about 150 pounds, which is collected in a tub. This wet sample then is reduced by hand in an 18-inch Jones splitter to a weight of 8 to 10 pounds and placed in a 2-gallon can with a tight lid. The cans are hauled to the mine sample plant where the water is removed with a vacuum filter. Filtered samples then are delivered to the assay-office bucking room, where they are dried, crushed, ground, and split for assay.

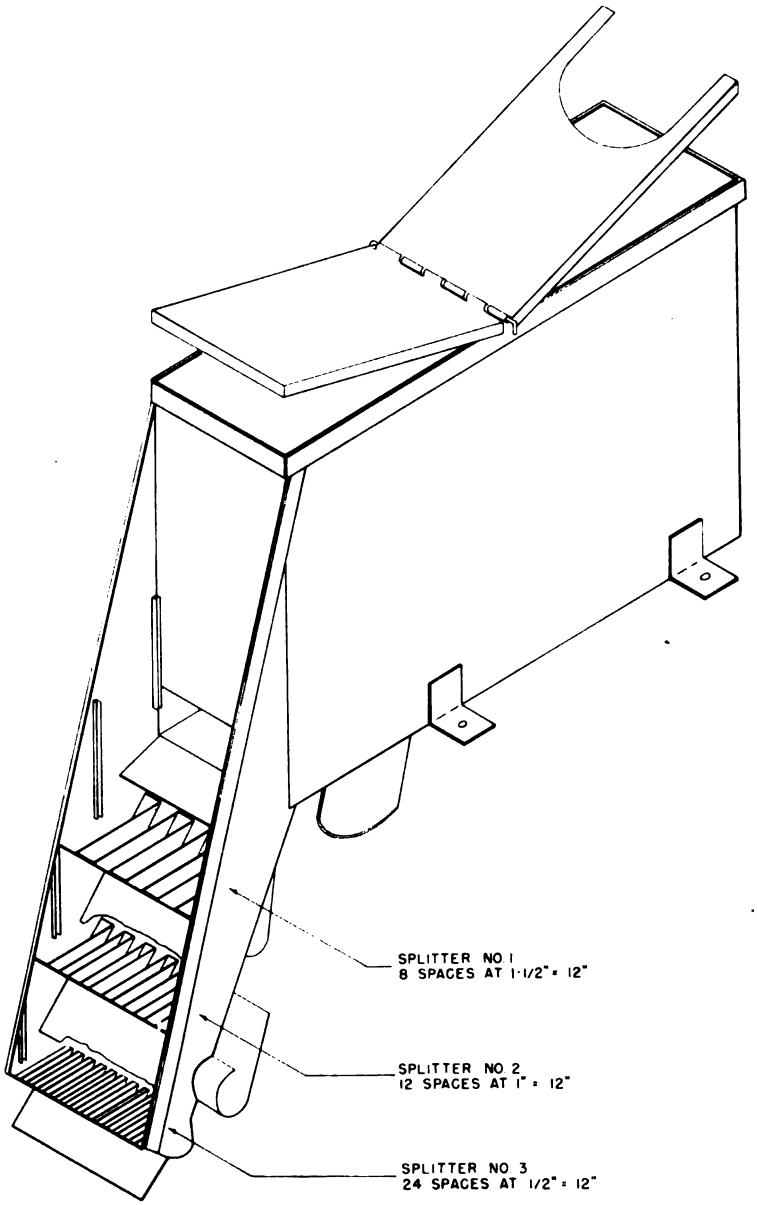

FIGURE 7. - Sketch of Sample Splitter.

At least once during each level interval a double sample is split at the drill; half is marked with the regular sample number and the other half is marked "Special sample." The location from which the special sample is taken is not disclosed by the sampler until the assay returns are received. This procedure has encouraged careful handling of samples by all concerned.

The drill crew comprises a drill operator and a helper. Sampling is controlled by the engineering department. A report (fig. 9, form 1) is completed in duplicate by the sampler; a copy remains at the drill site until the hole is completed, and the original is sent to the engineering office. At the end of the shift a report (fig. 9, form 2) is prepared showing the status of each sample taken during the day. When the assay of a sample is returned it is posted on a permanent record sheet (fig. 10, form 3). A check sample comparison sheet (fig. 10, form 4) is prepared to indicate the accuracy of the sampling. Finally, the drill samples are averaged by level intervals and posted to a permanent record (fig. 11, form 5).

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FIGURE 8. - Sample Splitter Mounted on Drill.

The surveyed position is plotted on a map, and the area of influence of each sample hole is ascertained. Every effort is made to adhere to a 400-foot grid with a center hole in each 400-foot square; however, the extremely rugged terrain makes regular location of sample holes impossible, and the spacing of some holes is quite irregular. The area of influence of each hole is determined by drawing connecting lines with each of the surrounding holes, bisecting these lines, and extending a perpendicular line until it connects with the perpendicular line from the adjoining hole, as shown in figure 12.

A tonnage factor is determined. Assuming a level map scale of 200 feet to the inch, a bench height of 50 feet, and the weight of material as 1 ton per 12.5 cubic feet of ore in place, this factor is developed as follows:

$$\frac{200 \times 200 \times 50}{12.5} = 160{,}000 \text{ (factor = tons per square inch of map area).}$$

Application of this factor and calculation of grade for the shaded area in figure 13 are as follows: From the hypothetical level map, the area of each polygon is determined in square inches with a planimeter and noted on the map in the polygon by figures and symbols for checking. The data are then tabulated.

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SAMPLER'S LOG SHEET

Hole No._____Date_____

Shift_____

Sampler_____

Driller_____

Helper_____

Depth at start of shift_____

Depth at end of shift_____

Footage drilled_____

Size of bit used_____

RUN NO.	DEPTH FROM TO	SAMPLE SIZE	BIT SIZE	REMARKS

Water level in hole_____

Casing run_____Casing size_____

General remarks on shifts operations:

FORM NO. 1

FORM NO. 2

ENGINEERING DEPARTMENT

SAMPLING

SHIFT REPORT

PHELPS DODGE CORPORATION

Morenci Branch

Hole No.....

Date .....

Shift .....

SAMPLE No.	DEPTH From	DEPTH To	SAMPLE SPLIT	BIT SIZE	COLOR SLUDGE	ASSAY SAMPLE PROGRESS Bailed	Split	In Filters	Comp.		CHAR. SAMPLE Inc.	CHAR. SAMPLE Comp.	CONC. SAMPLE Inc.	CONC. SAMPLE Comp.

	Start Shift	End Shift	Remarks:
DEPTH			
REAMING			
CASING			
WATER			
SAMPLER			

FIGURE 9. - Sampler's Log Sheet and Shift Report.

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PHELPS DODGE CORPORATION
MORENCI BRANCH
MORENCI, ARIZONA

CHURN DRILL SAMPLE ASSAYS

Hole No.
Drill No.
Collar Elevation
Sheet of

Smpl. No.	Depth	Total Copper	Oxide Copper	Level Average	Level	Smpl. No.	Depth	Total Copper	Oxide Copper	Level Average	Level

FORM 3

PHELPS DODGE CORPORATION
MORENCI BRANCH
MORENCI, ARIZONA

Check Sample Comparison

Hole No.
Drill No.
Sheet of

Special No.	Assay	Regular No.	Assay	Differ-ence	Special No.	Assay	Regular No.	Assay	Differ-ence

FORM 4

FIGURE 10. - Churn-Drill Sample Assay and Check-Sample Comparison Reports.

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PHELPS DODGE CORPORATION
MORENCI BRANCH
MORENCI, ARIZONA

Churn Drill

Assays by Levels

Hole No.
Drill No.
Collar Elevation
Sheet of

Level	Depth	Total Copper	Level	Depth	Total Copper	Level	Depth	Total Copper
5400			4600			3800		
5350			4550			3750		
5300			4500			3700		
5250			4450			3650		
5200			4400			3600		
5150			4350			3550		
5100			4300			3500		
5050			4250			3450		
5000			4200			3400		
4950			4150			3350		
4900			4100			3300		
4850			4050			3250		
4800			4000			3200		
4750			3950			3150		
4700			3900			3100		
4650			3850			3050		

Date Started	Remarks
Date completed	
Collar Elevation	
Bottom Elevation	
Total Depth	
	Co-ordinates N W

FORM NO. 5

FIGURE 11. - Churn-Drill Assays by Levels Report.

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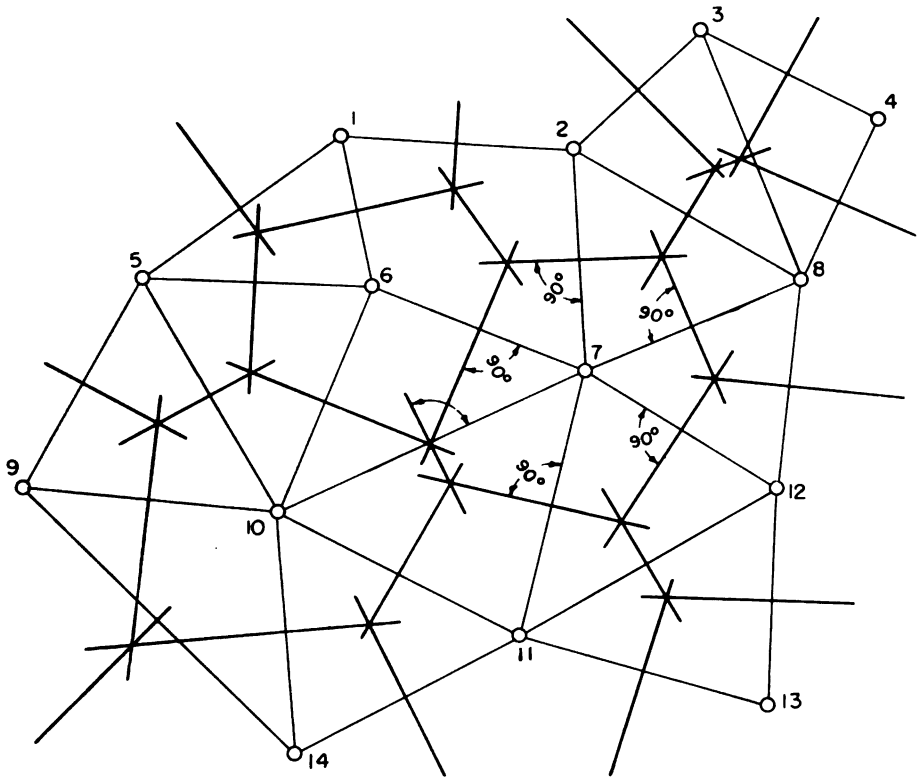

FIGURE 12. - Method of Determining Area of Influence of Each Drill Hole.

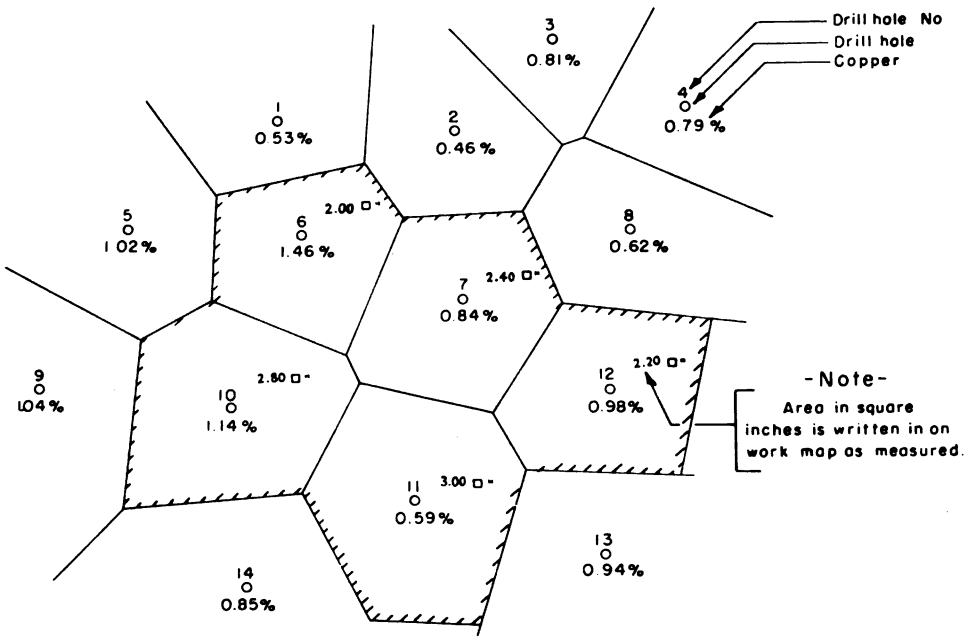

FIGURE 13. - Hypothetical Level Map.

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Hole No.	Area (square inches)	Grade	Area x grade
6.....	2.00	1.46	2.92
7.....	2.40	.84	2.02
12.....	2.20	.98	2.16
10.....	2.80	1.14	3.19
11.....	3.00	.59	1.77
Total.....	12.40		12.06

$$\text{Average grade} = \frac{12.06}{12.40} = 0.97.$$

$$\text{Tons} = 12.40 \times 160{,}000 = 1{,}984{,}000.$$

Thus, the area in the example is estimated to contain 1,984,000 tons of 0.97-percent copper ore.

Ore reserves are carried by levels. When open-pit mining of ore was begun in 1942, the ore body was estimated to contain 284,000,000 tons assaying 1.036 percent copper.18/ The pit limits at that time were projected on 45° overall slopes and provided for mining 230,000,000 tons of ore.

The tonnage and grade of present reserves are not available for publication.

DEVELOPMENT

Preliminary development of the Morenci open-pit mine has been described by Walter C. Lawson.19/ The topography surrounding Morenci is extremely rugged and mountainous. (See fig. 1, p. 2.) When development was started, routes to the proposed sites of the crushers and waste dumps crossed deep canyons and steep cliffs. The average thickness of the capping overlying the ore was 216 feet and the maximum 500 feet. The vertical extent of the ore body was 1,300 feet. It was desirable that ore for large-scale concentration tests be uncovered rapidly and tested so that the concentrating-plant design could be completed and the plant constructed when the mine was ready for steady production. Much preparatory construction was required, such as roads, railroads, shop and tool buildings, restaurant, offices, and townsite.

Rail haulage was planned after roadbeds were completed and benches established. However, stripping could be started with much less preparatory work if trucks were used, and approach tracks to the mill and service tracks to the upper benches could be put in semipermanent position at the start. From 1937 to the end of 1940, approximately 28,916,000 tons of stripping was completed. Disposal of waste material was planned to tie in with railroad construction by dumping to preliminary alinement. After July 1, 1940, truck haulage was supplemented by rail haulage.

18/ Work cited in footnote 16, p. 10.
19/ Work cited in footnote 16, p. 10.

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By the end of 1941, 49,183,602 tons of waste had been removed from the pit area, stripping operations planned in advance of mining had been completed, and the mine was developed to permit a daily ore extraction of 25,000 tons. From the test-pit area, 843,493 tons of ore had been mined and tested. The main rail haulageway was in good operating condition. All essential parts of the concentrator and the smelter were nearing completion, and one unit of the powerplant was almost ready to run.

The final development plans are based on 37° overall slopes. Banks are 50 feet high, and bench operating widths are approximately 100 feet. (See fig. 14.) When a bench is not being operated its width is sometimes reduced. A ruling grade of 4.0 percent, compensated for curvature, is used on switchbacks in favor of the load; 3 percent is used on grades adverse to the load. The general arrangement of the mine and plant (fig. 3) was planned so that 85 percent of the material would be moved over favorable grades. Dump tracks are approximately level. The haul from the mine to the crushers is about 1-1/2 miles over a connecting track grade of 0.25 percent, favorable to loads.

Except for the fact that a much greater proportion of the material moved during development was hauled by trucks than by trains, the operations of development and mining are identical.

MINING

The Morenci ore body forms a rough oval with the minor axis 1 mile long and the major axis 1-1/4 miles long. In plan the general shape of the open pit is that of a crescent with the open end toward Chase Creek on the east. (See fig. 1, p. 2.) There are 27 bench levels 50 feet high and ranging in altitude from 4,350 to 5,650 feet. Mining benches advance westward into the high ridge that trends southward from Coronado Mountain and terminates in Copper Mountain. Much of the waste is moved around the north horn of the crescent; both ore and waste are moved south. (See fig. 3, p. 4.) Some waste from the higher levels is taken west, over the ridge, to the Producer dump.

Development of the open-pit mine was begun in September 1937, and 205,000,000 tons of ore and 420,000,000 tons of waste had been removed by September 1956. In September 1956, the mine was producing 52,000 tons of ore and 118,000 tons of waste per day. Of this amount, 30,000 tons of waste was being hauled by truck and the remainder by rail.

The details of development and mining are essentially the same. The cycle of operations consists of breaking, loading, hauling, and disposal of ore and waste. Holes 12 inches in diameter are drilled along 50-foot banks with churn drills; rotary drills are on trial. These holes are loaded with free-running bag powder and blasted with Primacord fuse. The amount of secondary drilling is small. Ore and waste trains are loaded by 6-yard, 7-yard, and 8-yard electric shovels and are pulled with 1,200- or 1,750-hp. diesel-electric locomotives over a track with a 4-percent grade favoring the load. Main-line track is laid with 133-pound rail and bench track with 90-pound rail. There are about 70 miles of standard-gage railroad track and more than 100 miles of truck road in the mine.

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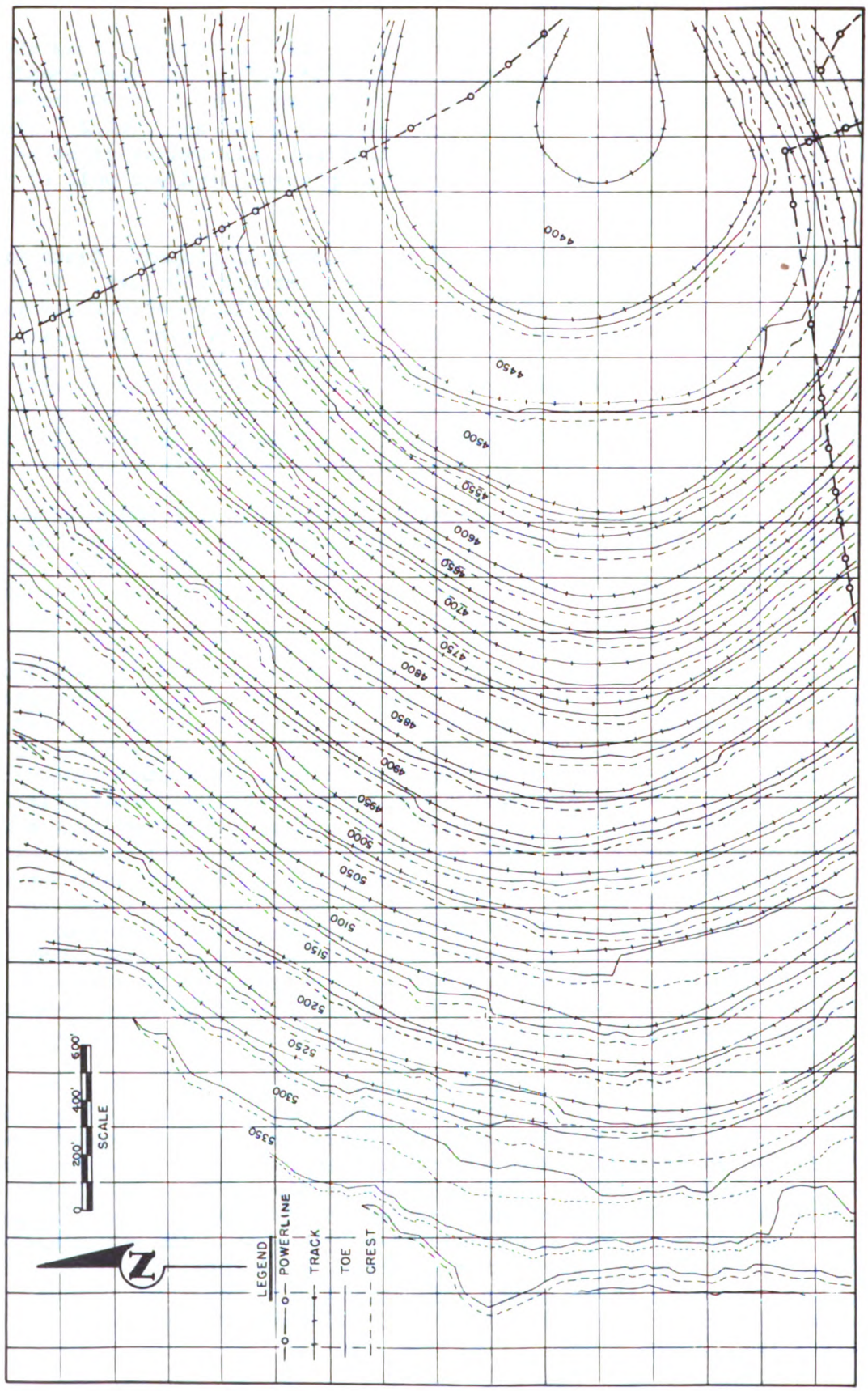

FIGURE 14. - Plan of Operating Benches, Morenci Mine, Arizona.

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Rail traffic is directed by straight manual signals in fringe areas, automatic blocks in intermediate areas, and central traffic control in the mine to mill haulage.

Breaking Ground

In the Morenci open-pit mine, drilling and blasting fall naturally into three catagories as follows: Primary drilling and blasting in the pit area for production; secondary drilling and blasting in the pit area to augment primary blasting; and drilling and blasting for road construction, both inside and outside of the pit area. Each type requires different equipment and methods and will be discussed separately.

The drilling and blasting department has about 230 employees. An office building is provided where reports are collected and records and general reports compiled by a clerk. An office for the department foreman and a conference room for planning and coordinating drilling and blasting activities are available. Drill assignments are scheduled and posted on a bulletin board near the mine entrance so that employees will know where to find the machines to which they are assigned.

Primary Drilling and Blasting

Primary blastholes are drilled along the crest of a 50-foot bank to a depth of 8 feet below digging grade (fig. 15). Spacing averages 24 feet along the bank, and the holes are set back 10 to 15 feet from the crest. Long bank blasts are preferred. The average bank blast contains approximately 60 holes,

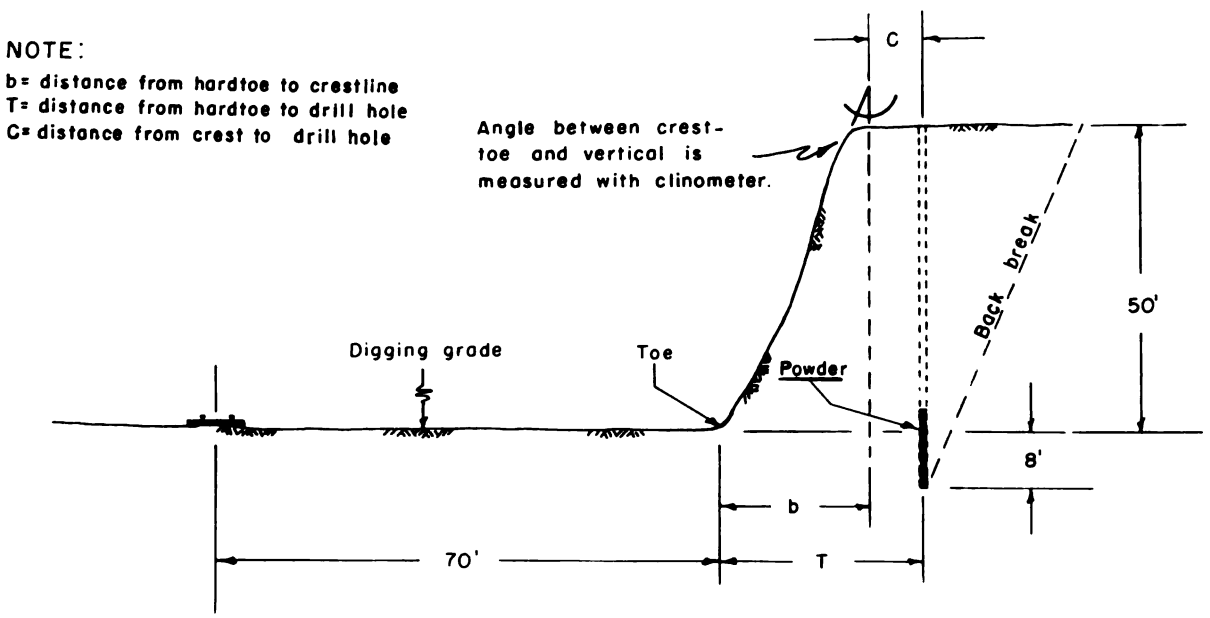

FIGURE 15. - Arrangement of Primary Drill Hole in Bank, Morenci Mine, Arizona.

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but blasts that contain over 100 holes are not uncommon. Drill holes are spotted in a single row; however, where a sharp point projects outward from the general line of the crest, an extra hole or two may be drilled to avoid sharp breaks in the trend of the bank.

Some primary drilling is completed with a small rotary drill which drills 7-3/8-inch-diameter holes with a tricone bit. This machine was operated 88 shifts during August, September, and October 1956. It drilled 20,630 feet of blasthole for an average of 234.0 feet per drill-shift; 26 bits were used for an average duty of 793.5 feet per bit. When the mine was visited late in 1956, one large rotary drill was being used. This machine is capable of drilling a 12-1/4-inch-diameter blasthole. (See fig. 16.)

The large rotary drill is mounted on 42-inch crawler-type treads and is equipped with three hydraulic jacks that quickly raise and level the machine for drilling. Tricone bits drill a 12-1/4-inch-diameter hole. The drill steel is 7 inches in outside diameter and is hollow to provide a passageway for compressed air, which cools the bit and removes cuttings from the hole. Two compressors, each having a capacity of 686 c.f.m. and each driven by a 125-hp. electric motor, are mounted on the machine frame to provide air.

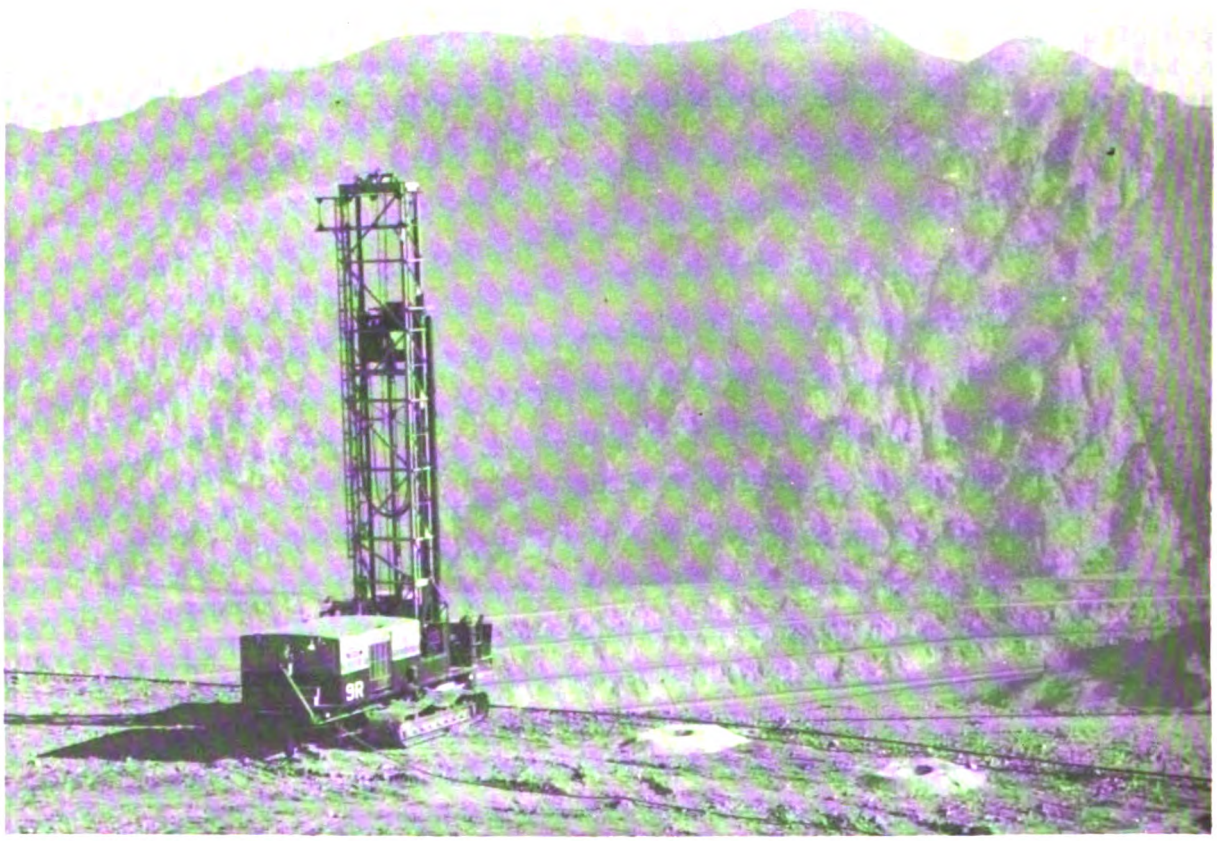

FIGURE 16. - Rotary Drill.

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Power for rotating the bit is regulated by a Ward Leonard control; rotating speed averages about 40 r.p.m. in hard ground. Electric power is carried to the drill in an insulated cable at 4,160 volts and reduced to 440 volts direct current with a motor-generator set.

Drill-steel sections are 32 feet 8 inches long; thus, the average hole of 58 feet at Morenci can be drilled with two drill-steel sections. These sections are added or removed by a remote-controlled, power-driven, tool-handling unit. The operator's station is next to the drill hole where he can see what is happening at all times.

From the start of open-pit mining in September 1937 to December 1956, when the mine was visited, the churn drill has been the workhorse of the primary drilling crew. Two types of drills have been used, a light- and a medium-weight spudding-type machine. The light machine drills a 9-inch hole, and the medium-size machine drills a 12-inch hole. The heavier machine has replaced the lighter one.

The heavy churn drill now used at Morenci has an all-steel welded derrick supported by 10-point cantilever-type braces. The spudding sheave is rubber-cushioned. Direct-drive drilling motion is powered by a 40-hp. electric motor. The machine has crawler-type mounting and can be leveled by hydraulic jacks for drilling. Bits are changed with a power-driven tool wrench equipped with a torque indicator.

In order to break as much ground as is mined each day, approximately 2,600 feet of blasthole must be drilled. Most of this is done with 24 churn drills that are operated 26 to 28 drill-shifts per day. During the first 9 months of 1956, churn-drill crews averaged 97 feet of blasthole per drill-shift. New churn-drill bits, approximately 5 feet long, can be sharpened an average of 87 times and drill 71 feet per sharpening.

Primary blastholes are loaded by a powder crew under the supervision of a loading foreman. The area containing the holes to be loaded is first marked off for safety. The first step in loading a bank blast is to determine the load or amount of powder for each hole. A system designed to provide uniform loading has been worked out at Morenci.

The depth of the hole, the distance to the next hole, and the distance from hole to crest are measured and recorded in a notebook on the powder loading report (fig. 17). From the crest of the bank in line with the drill hole, the toe is sighted with a pendulum-type clinometer and the angle of inclination determined. (See fig. 15.) A table has been prepared in which the distance b, from hardtoe to crestline, has been computed for a bank 50 feet high and tabulated opposite the angle. From this table the foreman reads the distance b, then (fig. 15) mentally adds the distance C, from crest to drill hole, and records the toe distance T on the powder loading report. He now is ready to determine the burden and powder load for the hole.

Computing the burden involves two variables, the average toe and the hole spacing. The average toe is one-half the sum of the crest and toe measurements;

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TABLE I

8 Yard spacing							
		Powder factor					
Avg. Toe	Burden	0.65	0.70	0.75	0.80	0.85	0.90
12	1630	21	23	24	26	28	29
11.5	1560	20	22	23	25	27	28
11	1500	19	21	22	24	25	27
10.5	1430	19	20	21	23	24	26
10	1360	18	19	20	22	23	24
9.5	1290	17	18	19	21	22	23

POWDER LOADING REPORT

Level ..... Date .....
Coordinates from ... to ... Weather ..... Foreman .....

Hole	Depth	Spacing Hole	Spacing Crest	Toe	Avg. Burden	Burden Cu Yds.	Powder	Stem	Powder	Stem	Blast No.
36	60	7	3	13	8	950	17		3	41	
37	60	7	4	13	8.5	1010	18		3	42	En 3025548B
38	60	8	5	13	9	1220	22		1	42	Old works
39	—	9	5	17	11	1725	No load				" "
40	60	8	5	13	9	1220	24		5	33	

FIGURE 17. - Tables From Notebook of Blasting Foreman.

it is the same as the "avg. burden" on the powder loading report. A table has been prepared for each hole spacing. A typical table for 8-yard spacing is shown in figure 17. The average toe is given in the left-hand column, the burden in cubic yards in the second column, and the powder load required to satisfy various powder factors in the remaining columns. The load is shown in units of 50-pound boxes and the powder factor in pounds per cubic yard at the top of the column. When the average toe for a hole has been determined and a loading factor selected, the charge for a drill hole can be read directly from this table.

Powder is delivered to the blast site in a covered truck (fig. 18) and stacked approximately 15 feet from the holes. Stemming is delivered in special dump trucks from a conveniently located bin (fig. 19). Provision is made at Morenci to load ore into 40-yard dump cars after it has passed the fine crushing plant; this ore is hauled to the stemming bin and used for stemming.

A 50-pound case of free-running powder contains four bags that weigh 12-1/2 pounds each. In completely dry holes no primer is necessary. Two strands of plastic-wire-countered Primacord are weighted with a bag of powder and lowered to the bottom of the hole. When large-diameter holes are loaded, the unopened bags of powder are dropped into the hole, but when smaller diameter holes are loaded the bags are opened and the powder is poured into the hole. As the powder is placed in the hole the Primacord must be held straight and taut. This is done with a light tripod, from which is suspended a heavy

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FIGURE 18. - Powder Being Unloaded and Stacked Near Drill Hole.

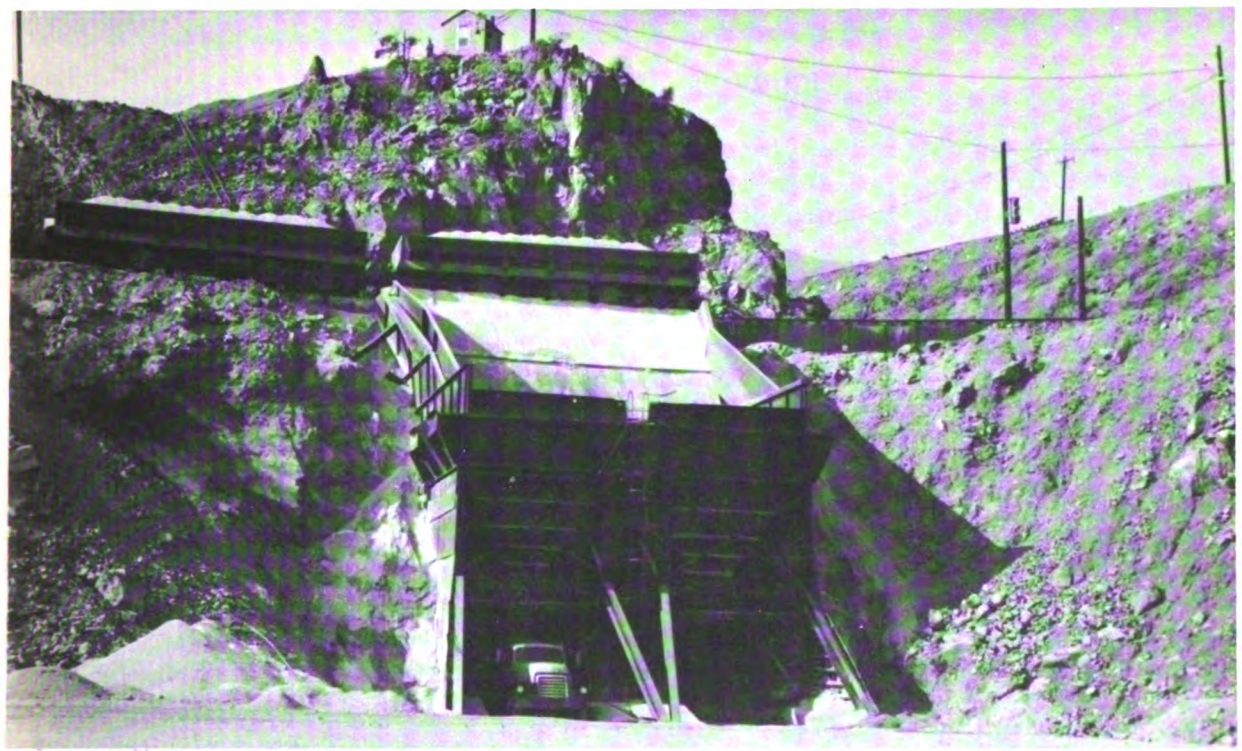

FIGURE 19. - Stemming Bin.

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coil-type spring to which the Primacord is fastened. Stemming is poured directly into the blasthole by a truck equipped with a Dumpcrete bed and a pouring spout. (See fig. 20.)

FIGURE 20. - Stemming Truck.

Bag powder is not loaded into wet blastholes. Where only a little water remains after drilling, gelatin is loaded until the powder column is above the wet zone, then loading is completed with bag powder. Gelatin powder comes wrapped in cartridges of two sizes - 8 inches in diameter by 10 inches long or 10 inches by 12 inches. When gelatin powder is to be used, a primer cartridge is made first by passing one end of the wire-countered Primacord completely around the cartridge and tying the end to the long length of Primacord. The primer cartridge is loaded into the hole, then the additional cartridges are split or quartered and dropped.

As the holes are loaded, the powder foreman completes the powder loading report (fig. 17). When all scheduled holes have been loaded, a single strand of plain Primacord is strung the length of the shot and all down lines are connected. Then, after due provision for safety, the blast is fired with an electric cap and a blasting machine. Occasionally, particularly in the harder oxidized capping, toe holes are used to relieve bank holes. The toe holes are always fired first by using a delay connector between them and the bank holes. Figures 21, 22, and 23 show a bench before, during, and after a blast. Blasting practice at Morenci results in about 5.0 tons of broken rock per pound of powder and about 78 tons per foot of primary drill hole.

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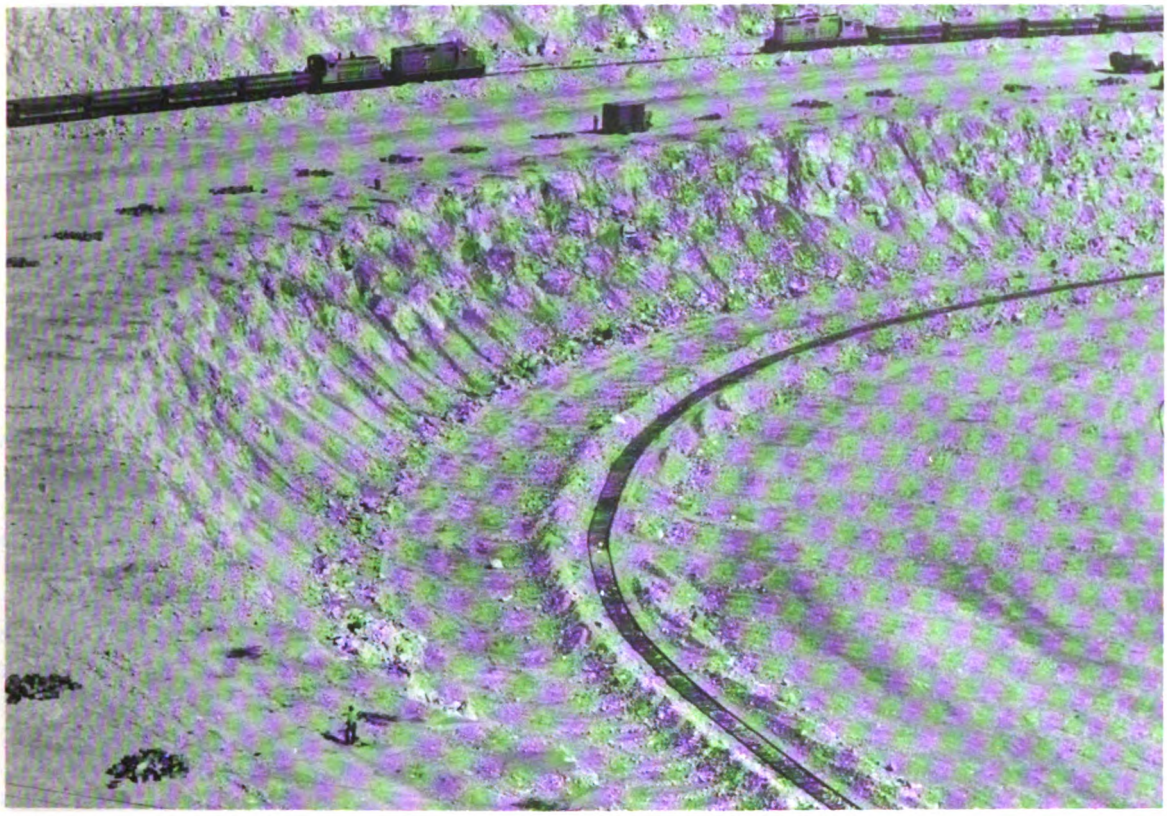

FIGURE 21. - Face of Bank Before Blast.

FIGURE 22. - Blasting a Typical Bank in Ore.

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FIGURE 23. - Face of Bank After Blast.

FIGURE 24. - South Switchback and Shop Area.

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Secondary Drilling

Secondary drilling in the major part of the Morenci mine is of minor importance. Less than 1 percent of all blasting in the pit is secondary. Large boulders are drilled using a tractor-mounted compressor or one of the heavier toe-hole machines and blasted. Hard bottom is drilled and blasted before the next bank blast is fired.

Construction Drilling

Late in 1956 an intensive construction program was in progress at Morenci; its objective was to move the series of switchbacks at the southern end of the mine (fig. 24) and make available a large block of ore. This change required the relocation of several miles of track in rough terrain, comprising considerable massive bedded quartzite and cherty limestone. Much of the drilling was done from an access road.

A small rotary drill, mounted on a medium-size crawler-type tractor, is used for vertical holes. The drilling mechanism is mounted on the rear and is operated through a power takeoff by the tractor engine. The compressor is mounted on the front end of the tractor and driven by a separate engine. Both engines use diesel fuel. The machine is equipped with a standard 5-5/8-inch tricone bit mounted on 3-1/2-inch-diameter hollow steel. The bit turns at speeds that range from 25 to 300 r.p.m. It is cooled and cuttings are cleaned from the hole with compressed air. During a period of 3 months in 1956 this machine operated 74 shifts and drilled 10,885 feet of hole; bit life averaged 222.1 feet.

Because of the steepness of the terrain, much of the roadbed could be broken more easily and cheaply by drilling horizontal holes in the slope from a rough access road near the elevation of the final roadbed than by drilling vertical holes. A Drillmobile, built by one of the regular manufacturers of drilling equipment to specifications provided by employees of the Morenci mine, is used for this work. This machine also is used for toe holes in the mine. The Drillmobile has a standard 4-inch-bore, drifter-type machine mounted on an 18-foot shell suspended from two arms. The arms can be raised or lowered by hydraulic controls, thus elevating or depressing the angle of the hole. Steel 1-1/4 inches in diameter is made up in 16- and 32-foot lengths for this machine. Air is supplied by a 315-c.f.m. compressor and water from a tank. All equipment is mounted on a standard tractor-type chassis that is self-propelled. The machine has a road speed of 4 m.p.h.

Because the Drillmobile travels at a relatively slow speed, the same equipment has been mounted on a standard 10-ton truck chassis (fig. 25). Two of these units, called mobile drills, are available and are used for drilling toe holes or hard bottom in the mine and for construction work. Jackhammer work is necessary, and a 210-c.f.m. compressor has been mounted on a standard 2-ton truck. Water tanks and hose reels are provided. A two-man crew operates the unit; each man operates a jackhammer when drilling.

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FIGURE 25. - Mobile Drill.

When a light, highly mobile unit is required a tractor with self-contained compressor and a 2-1/2-inch drill mounted on the rear is used. This machine is used on boulders or hard toe where 4- to 6-foot holes are effective. It will drill at any angle.

Table 2 shows the relative performance of the various drilling units, and table 3 shows bit use.

TABLE 2. - Drilling rates for various units at Morenci mine

Type of unit	Diameter of hole, inches	Feet per shift
Churn drill.....	10 - 12	97
Heavy rotary.....	12-1/4	260
Medium rotary.....	7-3/8	234
Small rotary.....	5-5/8	147.1
Drillmobile.....	2-3/4	352.5
Mobile drill.....	2-3/4	291.7
Tractair.....	1-7/8	170.1
Wagon drill.....	2-3/4	167.8
Jackhammer.....	1-7/8	124.8

TABLE 3. - Bit use

Type	Size	Time sharpened	Average feet per use
Rotary	12-1/4	0	2,100.0
Do.	7-3/8	0	793.5
Do.	5-5/8	0	222.1
Churn drill		87	71.4
Air drill		6	118.0

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Bit Shop

Both churn-drill and air-drill bits are sharpened. The shop (fig. 26) is equipped with hot-milling equipment to sharpen steel jackbits; however, carbide insert bits now are used for all air-drill work. Bits of 2-7/8-inch gage are used by the heavy drills in 1-1/4-inch round steel. Bits of 1-7/8-inch gage are used by the lighter machines on 1-inch-diameter round steel. All bits are reground when the corners of the inserts become rounded. Approximately 300 bits are ground before the grinding wheel is discarded. The bits have both center and side airholes and are cross-type carbide insert bits with narrow wing and wide chipway. Normally bits are discarded because of wear on the reaming edge rather than the cutting edge.

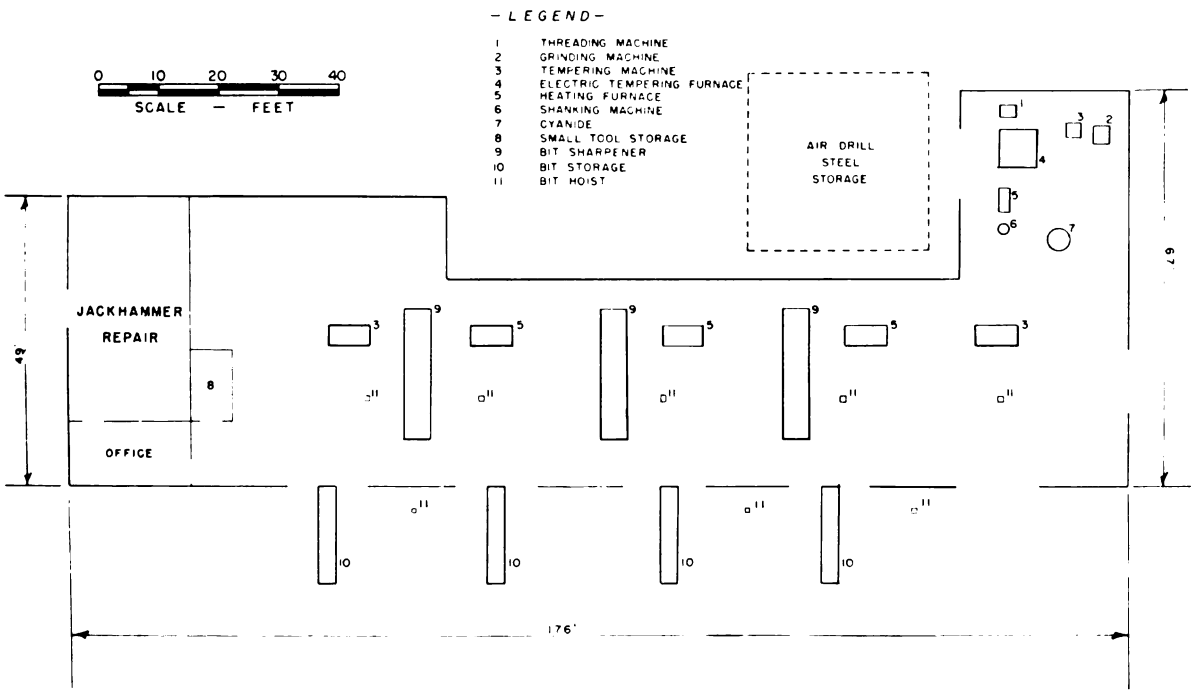

FIGURE 26. - Bit Shop, Morenci Mine.

Round steel is preferred. Steel is purchased in bulk; shank end and threads are forged and tempered in the bit shop. Lugged-type shank is used in all drills.

Blank churn-drill bits are purchased. Three heating and two tempering furnaces serve three mechanical sharpening machines. A reducing atmosphere is maintained in the natural-gas-fired furnaces by controlling the air. Temperature is measured with a pyrometer. The bits are tempered in agitated water. A hoist system serves the furnaces and machines and moves the bits to a storage and loading dock outside the shop, where they can be loaded easily on the bit delivery truck (fig. 27).

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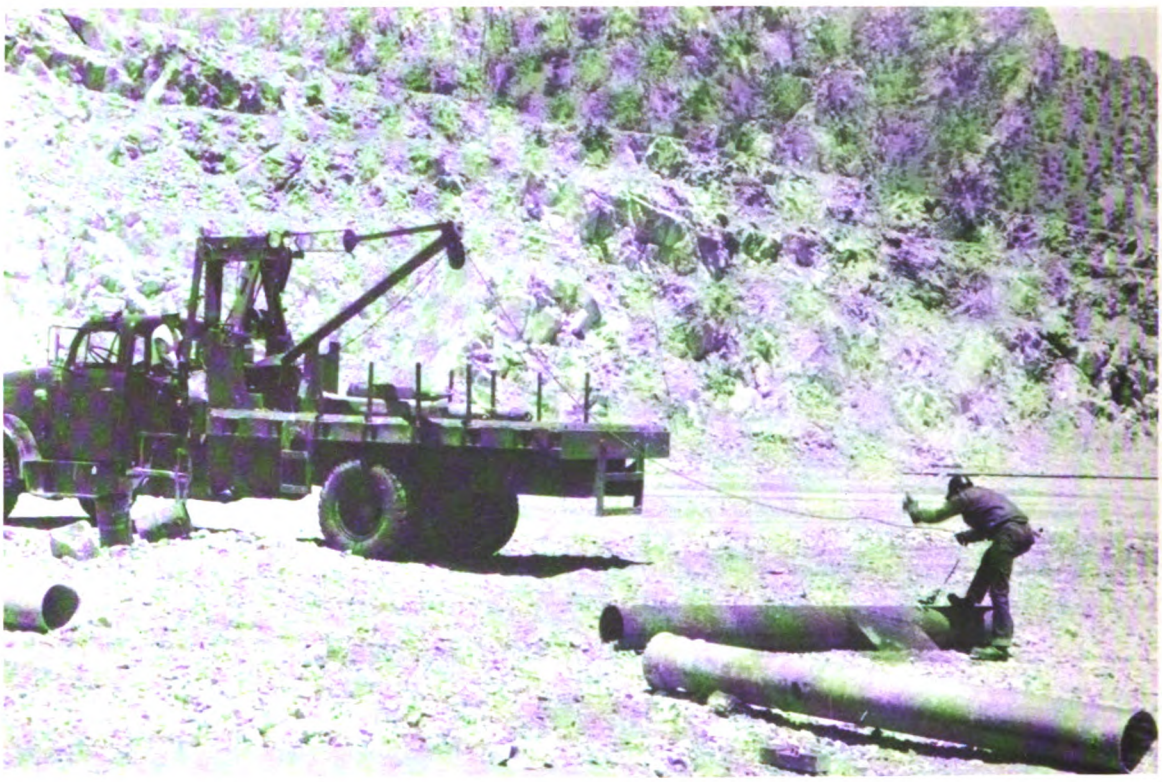

FIGURE 27. - Special Truck That Transports Churn-Drill Bits and Casing From Drill Shop to Mine.

FIGURE 28. - Shovel Loading a 35-Ton Truck.

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In addition to bit work, some tempering and hardening is done in the bit shop for the machine shop. A cyanide furnace and an electric furnace are available for this work.

Pipe Shop

A pipe shop is operated in connection with the drilling and blasting department and under the supervision of a pipe-shop foreman. A 2-inch pipe is laid along each open-pit bench to supply water to churn drills and sprinkler systems to prevent dust in the shovel pit.

Short lengths of 10- to 14-inch pipe are used to case blastholes through the first few feet of broken material. These pipes are sometimes damaged and bent during blasting and are repaired in the pipe shop. A special tool has been designed to reshape casing. It consists of a hydraulic cylinder between two rounded dies. The cylinder is activated through a long arm so that it can be pushed deep into a piece of pipe to press out a dent. When a piece of casing cannot be repaired, the damaged part is cut off and short pieces are welded together until a usable length is obtained.

Loading

Ore and waste are loaded by 20 full-revolving electric shovels into 40- or 43-cubic-yard railroad cars or into 25- or 35-ton rear-dump trucks (fig. 28). Sixteen shovels have a working weight of approximately 430,000 pounds each and are equipped with 6-yard dippers. Two shovels have 7-yard dippers and weigh approximately 455,000 pounds each, and two shovels have 8-yard dippers and weigh approximately 560,000 pounds each. All electric shovels are equipped with outside dipper handles and crawler travel mounts.

The 6-, 7-, and 8-yard dippers use five solid, alloy-steel teeth which are not sharpened but are turned several times during their useful life. Approximately 165,000 tons of material is loaded by a set of teeth before the teeth are discarded. Hoist cables are 1-1/2 inches in diameter on the 6-yard shovels and load about 500,000 tons of material before they are replaced. The 7-yard shovels use 1-3/4-inch diameter cables; tonnage loaded per cable replacement approximates that of the 6-yard machines.

The average loading time for a 10-car train is 50 minutes. Three moves and approximately 10 dipper loads of material are required to fill a 40- or 43-yard car, which carries an average of 82 tons (dry weight). The shovel crew consists of an operator and a helper. Shovel-shifts are distributed evenly over the three shifts contained in a 24-hour period. Unit production is 5,500 tons per shovel-shift.

Electricity, generated in a company-operated plant near the smelter, is conducted to the mine over a high line at 13,200 volts. About 0.206 kw.-hr. is required per ton mined. Four substations, each comprising three 500-kv.-a. transformers (fig. 29), reduce the voltage to 4,160; then the current is carried into the mine on a high line. A pole is placed on the line near the crest of each bank, and a lead is carried to a switchhouse at the bottom of

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the pole. (See fig. 22, p. 27.) An insulated cable is attached to an outlet in the switchhouse to carry power to the shovel.

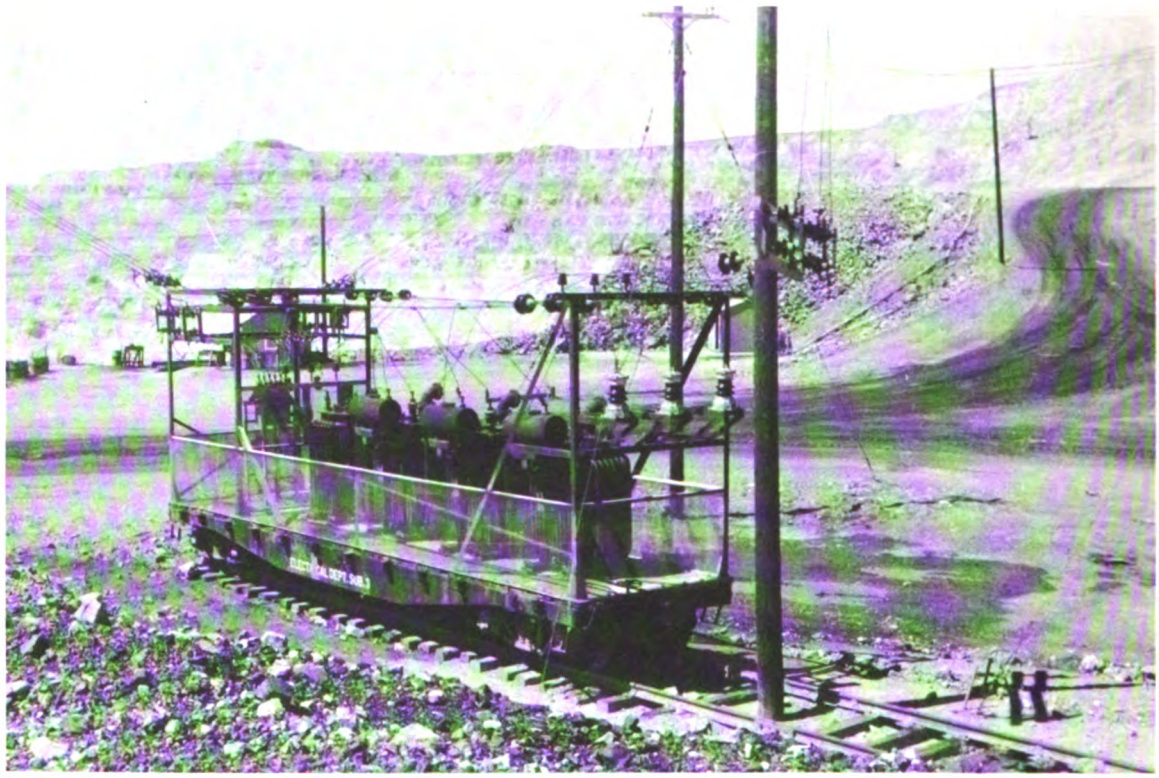

FIGURE 29. - Transformer Station Mounted on Flatcar.

Oil circuit breakers are provided for each substation and switchhouse. The circuit breakers are equipped with current relays to activate tripping in case of ground fault. Although the Morenci open pit is generally dry, tests have indicated that a shovel resting on dry ground is not adequately grounded without current relays connected to the ground wires in the shovel cables to help trip the switches. When a phase was grounded on the shovel without the current relay through the cable ground wires, a ground current of 8.75 amperes and 266 volts was necessary to trip the substation.20/

To obtain the desired ground resistance of 1.5 ohms or less, churn-drill holes are drilled 200 to 400 feet in depth and a 1,000,000-c.m. conductor is run the full depth and tied to the overhead ground. The holes are filled with coke and rock salt; water is run into them continuously. Two or more ground holes are provided for each substation. The overhead ground wire that is carried into the open pit on the high line is 2/0 copper wire. The cables that

20/ Berra, Felix, Ground Protective System of the Morenci Open-Pit Mine: Paper delivered at open-pit section meeting of AIME in Tucson, Ariz., on Dec. 3, 1951.

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carry power from the switchhouse to the shovel are No. 3 wire and have 5,000-volt insulation. Three ground wires, with a total capacity equal to that of one No. 3 wire, are carried in the cable and are grounded to the shovel frame at the shovel end. The ground wires at the switchhouse end of the cable are connected around the switches to the 2/0 ground wire on the high line to the substation.

The ground circuit is checked every 2 weeks by grounding a phase of the feeder cable on the shovel frame. This checks the cable return and the switchhouse. One of the switchhouse relays is blocked to make sure that the substation trips. When a ground fault appears, the shovel is removed from service until the circuit is cleared. Sometimes, when the shovel is in ore during wet weather, the substation switch will trip, bypassing the switchhouse. Either way the fault is cleared, and men are protected from a "hot" shovel.

Transportation

The transportation of ore and waste at the Morenci open-pit mine has been described by Fenzi and Ormsby.21/ About 170,000 tons of ore and waste is transported each day; 30,000 tons is hauled in rear-dump trucks and the remainder in standard-gage railroad cars. Trucks are used for short hauls or on the higher benches to prepare track grade. Where the haul is relatively long, all ore and waste is hauled by rail. The ore haul by train in 1956 averaged about 3.0 miles. The waste haul by train averaged about 3.5 miles. The truck haul during the same period averaged about 3,500 feet.

Rail Haulage

The crusher and the Stargo Canyon waste dumps are on the 4480 level. Mining benches above the 4500 level are serviced by access switchbacks at each end, with a ruling grade of 4.0 percent favorable to loads. (See fig. 30.) The approach to levels below the 4500 level is adverse to the load, and here the ruling grade is 3.0 percent. About 2,700 tons is hauled per locomotive-shift with a fuel consumption of about 100 gallons per shift.

Trains comprise 8 or 10 side-dump cars of 40- or 43-cubic-yard capacity. Approximately 250 cars are in service. The same cars are used for ore or waste; they carry 82 tons of material. The brake system combines straight and automatic air operation, and cars are equipped with both empty and load brake equipment. Cars are of welded, light-weight, alloy-steel construction with roller-bearing trucks. The cars can be dumped from either side by two heavy air cylinders and have dual side-pivot drop doors. Dump and train lines are separate. A train crew consists of an engineer and a brakeman.

Locomotives of three types have been used in the Morenci open pit since rail haulage was started in 1940. The first locomotive placed in service was a 1,000-hp. diesel-electric type. This locomotive was introduced for switching service on the main-line railroads in the late thirties. It has many

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21/ Fenzi, W. E., and Ormsby, L., Rail Haulage at the Morenci Open Pit Mine: Min. Cong. Jour., vol. 42, No. 11, November 1956, pp. 86-90.

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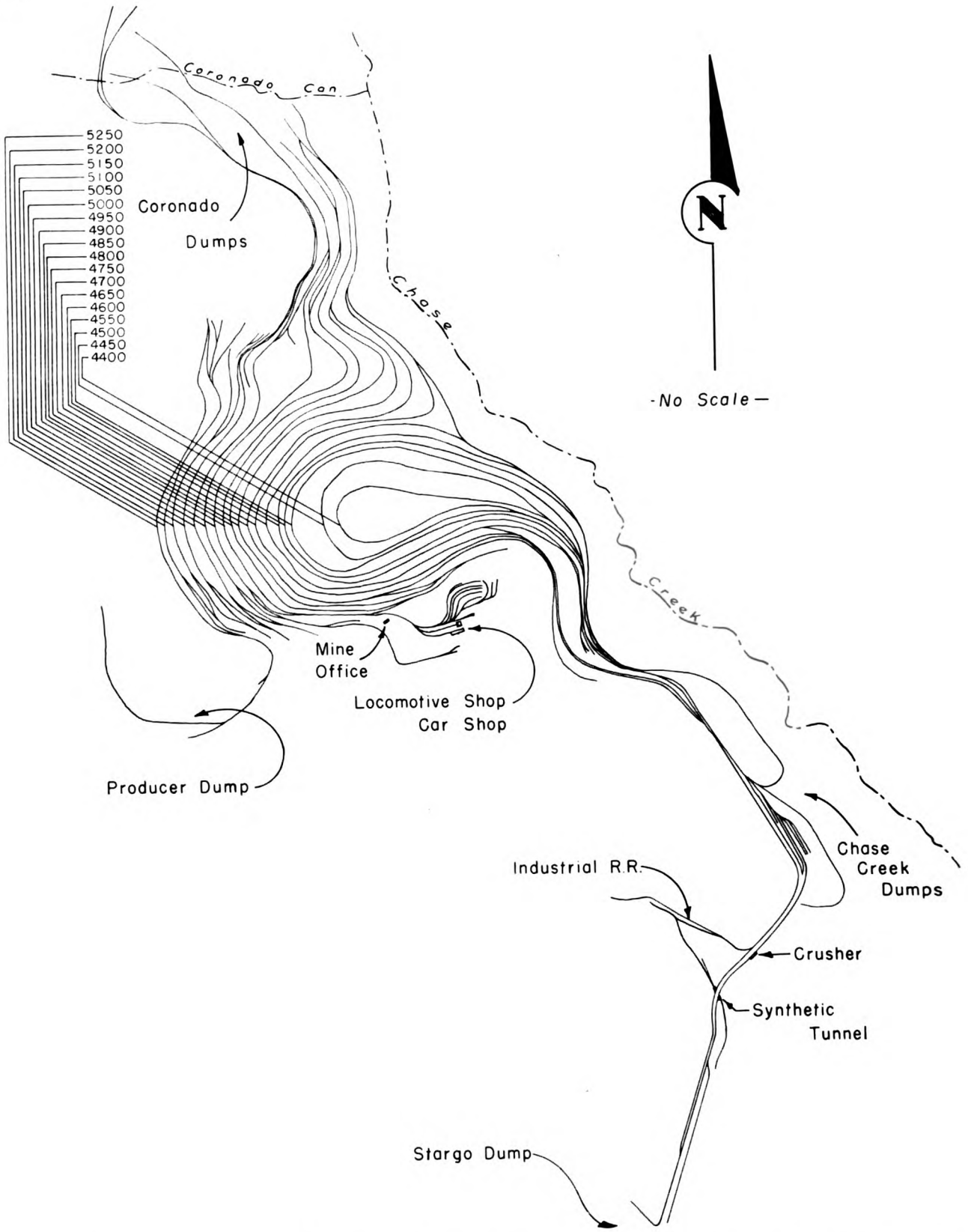

FIGURE 30. - Rail Haulage System at Morenci Mine. (Traced from map of Phelps Dodge Corp.)

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characteristics that make it particularly adaptable for mine haulage. Five of these units have been modernized through exchange of various units and raised to 1,200 hp. These locomotives will negotiate a 75° curve and handle an eight-car train at 7 miles per hour on the 4.0-percent grade; they have been used on levels above the 5000 level to haul waste to the Coronado dump north of the pit or to the Producer dump west of the pit. The haul from these levels to the dumps is generally short and the grades level. Under these conditions three trains can service two shovels. The availability of the locomotives has been more than 96 percent, and repair costs have been low. Seven 1,000-hp. diesel-electric locomotives are in service, but three are usually assigned to switching or work-train service.

A more powerful locomotive was desired when the mine reached full production. Trolley-electric locomotives were available. However, the character of of the ground at Morenci was such that heavy blasting was required, and the mining benches were narrow. A large tonnage of ore was needed per linear foot of available mining bench, and it was often necessary to make several cuts along a bank during a short period. Trolley wires and bonded rail are subject to damage from heavy blasting or frequent moves. These factors influenced the decision not to electrify the mining-bench tracks. Main-line haulage track including switchbacks on the ramps to the mining levels were electrified, and auxiliary power was provided for the loading bench tracks.

A 1,350-hp. trolley-electric locomotive, using 750-volt direct-current power, was designed specifically for service at Morenci. In addition to standard components, 500 ampere-hour batteries were added to furnish power for off-trolley operation. The batteries were adequate for level hauls on bench tracks that did not exceed 2,500 feet. By 1950 the length of the operating benches had been extended until the limit of the battery capacity was exceeded, and batteries were replaced with two diesel-electric auxiliary units of 290 hp., one on each end of the locomotive. The performance of these trolley locomotives, using trolley power on ramps and main line and auxiliary diesel-electric power on loading benches and dumps, was satisfactory. The locomotive handled an eight-car train up the 4.0-percent grade at 12 miles per hour and, in spite of the increased maintenance that resulted from the diesel-electric auxiliary units, had an availability of more than 90 percent.

Plans for track extension in 1955 called for electrification of an additional 5 miles of main-line track. Because of the high cost of this proposed electrification it was decided to replace the 16-trolley-electric locomotives with 1,750-hp. diesel-electric locomotives and thus eliminate all electrical track work. These locomotives originally were designed and built to be used as 1,500-hp. road switchers by the main-line railroads. After a series of improvements and modifications, the power was raised to a full-time rating of 1,750 hp.

The 1,750-hp. diesel-electric locomotive pulls a 10-car train up a 4.0-percent grade at the rate of 14 m.p.h. and may exceed 45 m.p.h. on level tracks. It is capable of rapid acceleration and will negotiate a curve of 39°; 17 of these locomotives are in use. Table 4 compares operating efficiencies of the three types of locomotive, and table 5 gives the operating cycle of the

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trolley-electric and 1,750-hp. diesel-electric locomotives. It should be remembered that operating conditions are not always the same.

TABLE 4. - Comparison of locomotive efficiency[1/]

Type of locomotive	Period	Tons per locomotive-shift	Length of haul, miles	Availability, percent
1,000-hp. diesel-electric	First 6 months, 1956	2,635	2.2	96.0
1,350-hp. trolley-electric	do.	2,284	3.0	90.0
1,750 diesel-electric....	do.	2,752	3.2	98.0

1/ Work cited in footnote 21, p. 35.

TABLE 5. - Train operating cycle

	1,350-hp. trolley-electric, percent	1,750-hp. diesel-electric, percent
Loading time	32.3	39.19
Haulage time	29.1	26.81
Dumping time	6.2	4.61
Dump at crusher	-	3.16
Crusher delay	.7	3.00
Servicing locomotive	2.6	2.41
Train repair	.8	.43
Shovel delay	3.1	4.90
Traffic delay	10.8	3.42
Power delay	2.3	-
Pusher delay	1.4	-
Miscellaneous	.2	1.78
Crew travel	10.5	10.29

Two factors control the track layout at an open-pit mine - topography and tonnage involved. This was particularly true at Morenci, where years of pit operation were necessary before access tracks could be built to both sides of the mine. The completion of the second set of access tracks (fig. 30, p. 36) resulted in a 15-percent increase in tons per shovel-shift because of improved train coverage. Main-line track in an open-pit mine is never static; it must be continually relocated to make additional ore available. The movement of the Morenci pit to the south will require more than 4 miles of roadbed and a new location for mine shops.

The problem of continually moving loading and main-line tracks has been given much attention by the operating department at Morenci. As labor rates continue to increase, conventional methods have been discarded for mechanized methods. The first major change was the use of bulldozers and conventional highway motor graders to prepare track grade. A rooter was introduced to tear out hard points and give a smooth final grade. Hand blocking (placing rocks under the ties to compensate for uneven subgrade) was eliminated. A bulldozer prepares 250 feet of rough grade per shift; a motor grader finishes 4,000 feet of grade per shift.

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The second notable improvement in track construction was the innovation of the panel method of laying track.22/ Panels of track the length of one standard rail are built in a yard especially designed and equipped for this purpose. (See fig. 31.) A jig (fig. 32) with spacing stops for ties and vertical uprights to govern rail gage is used when new panels are built. Standard panels consist of two standard-length rails fastened (with ends exactly even) to seventeen 7- by 9-inch by 8-foot crossties. All ties are equipped with tie plates except three (one near each end and one near the center of the panel). On each of these three ties is placed a spacing bar made of steel plate that is the same thickness as the regular tie plates; the bars are continuous for the full width of the track, and steel cleats on the inside prevent narrow-gage panels. Rails are placed by a locomotive crane (40-ton capacity and 50-foot boom), and 5/8- by 6-inch railroad spikes are driven with a pneumatic spike driver. Airhose is contained on a spring reel (fig. 33). The panel yard is operated two shifts per day.

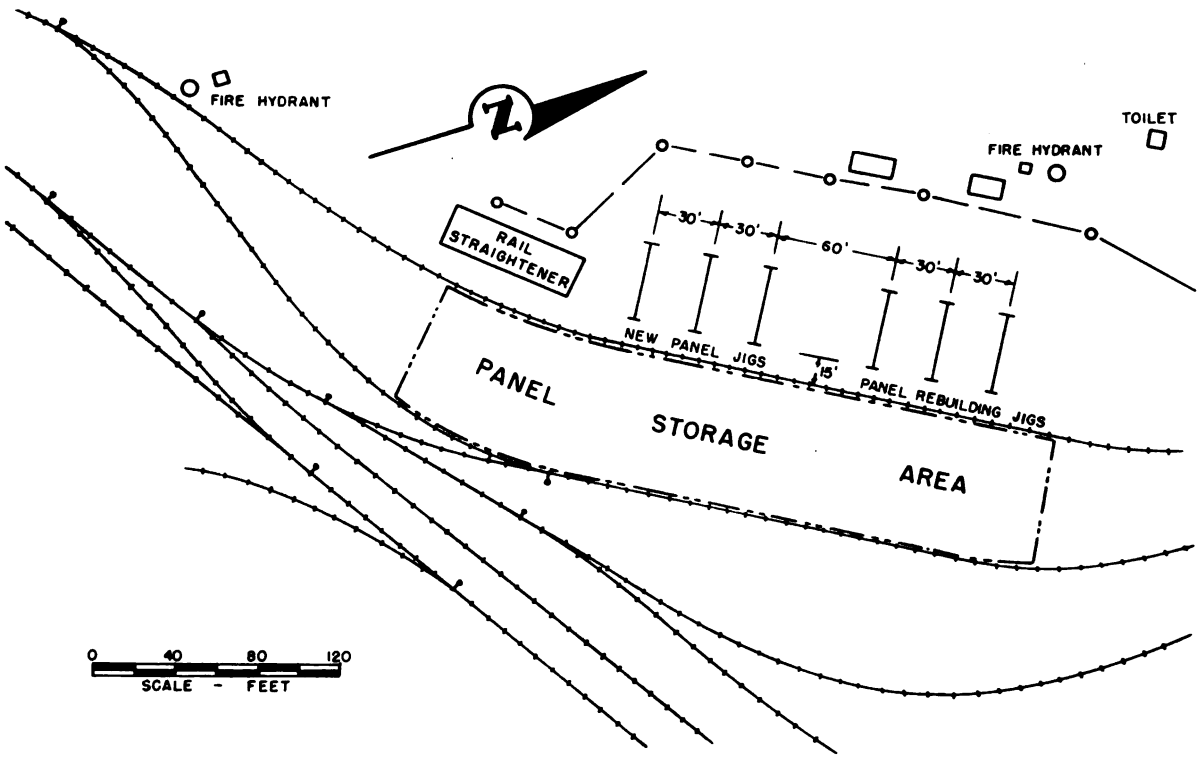

FIGURE 31. - Plan of Yard Where New Rail Panels Are Built and Used Panels Rebuilt.

Completed panels are picked up by the crane with two special rail clamps and a short sling and either placed in a storage pile or loaded on a flatcar for transportation to the job. Generally, nine panels are carried on a flatcar, and 20 flatcars are available for use in laying track. The locomotive

22/ Lawson, Walter C., Laying Panel Track at the Morenci Open Pit: Min. Technol., AIME, vol. 11, No. 4, July 1947, 13 pp.

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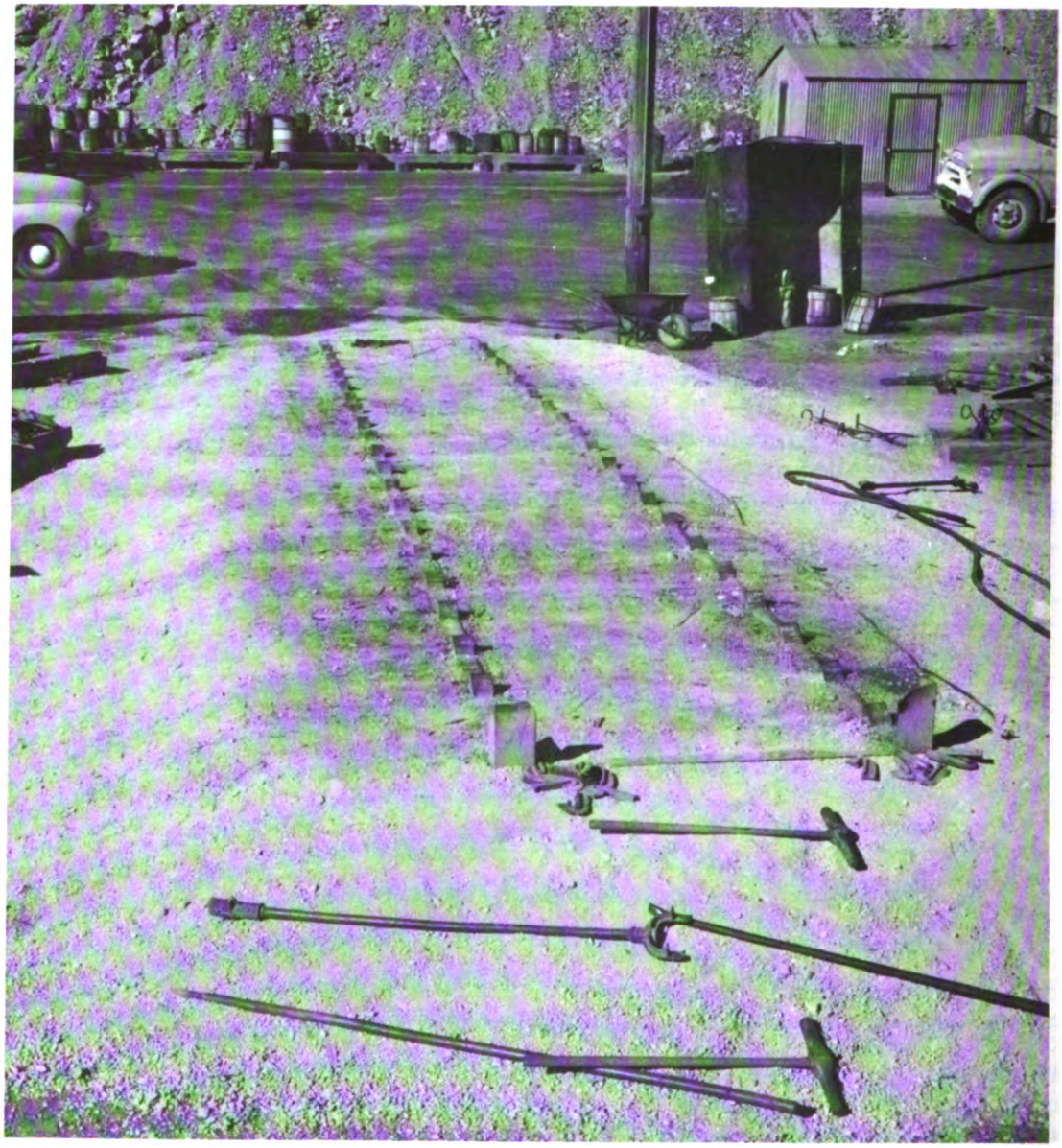

FIGURE 32. - Jig for Building and Repairing Panels.

crane lifts the panels from the flatcar and lays them in place on the grade that has been prepared. The panel is held by the crane operator until the joint has been matched by the groundmen. When panels are being laid on a curve a dutchman (short piece of rail) is inserted between the two rails on the outside of the curve, and the ties are respaced with a hammer.

The third improvement has been the mechanization of most track activities formerly done by hand. For example, rails are leveled with a power-operated jack, bolts are tightened with a power-operated wrench, ballast is tamped with a power ballast tamper (fig. 34), and spikes are driven with power-operated hammers. Wherever possible, power equipment has been substituted for human effort.

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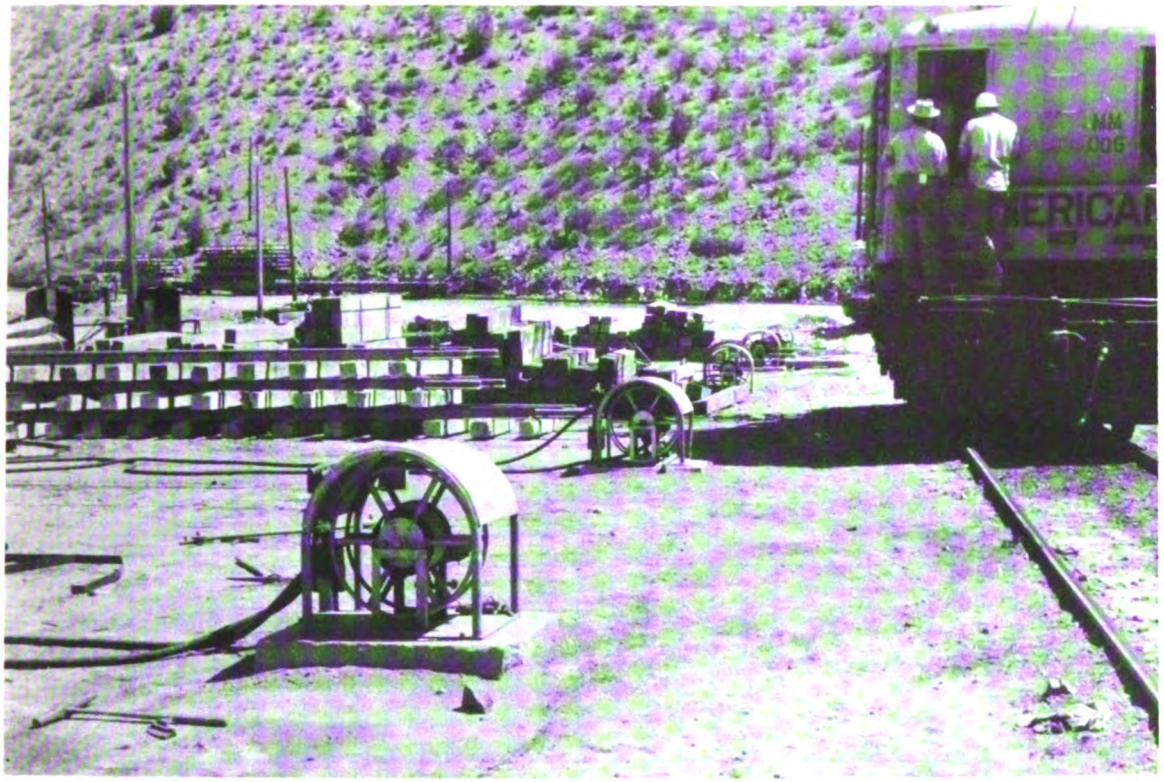

FIGURE 33. - Reel for Spiking Hammer Hose in Panel Yard.

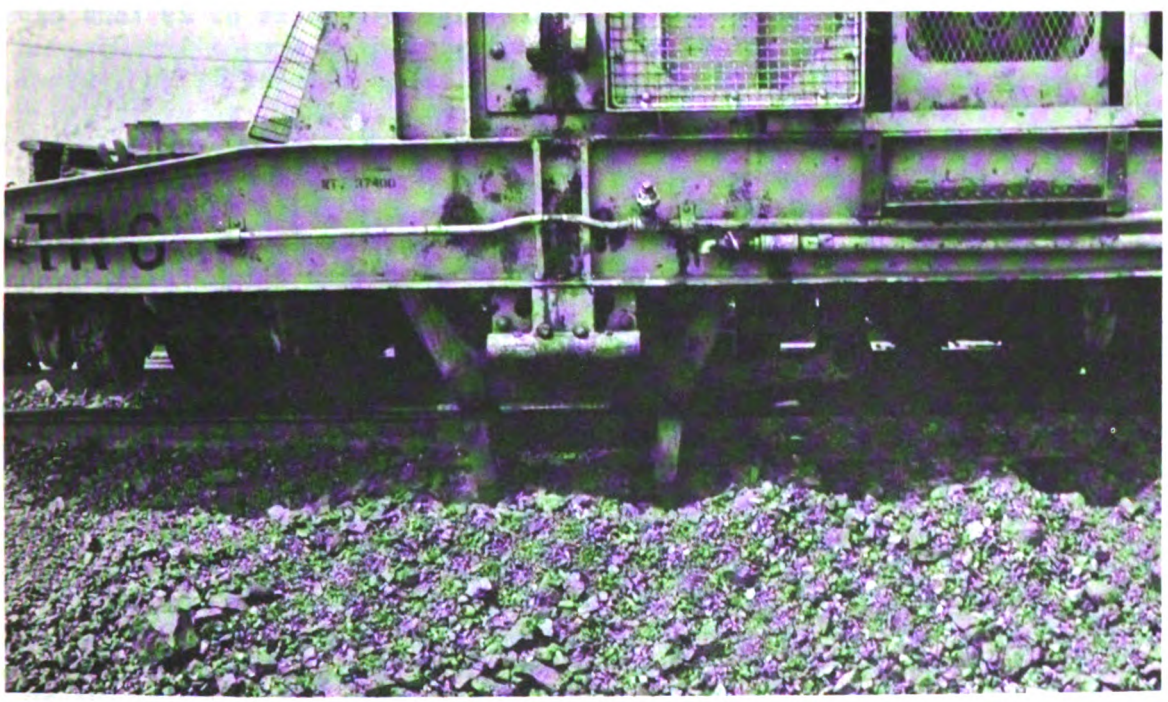

FIGURE 34. - Track Ballast-Tamping Machine.

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A fourth improvement has been the use of track ballast. A specially designed car was built to distribute ballast. (See fig. 35.) A revolving broom (fig. 36) for sweeping the finished roadbed is mounted on the rear of the car. Slag from smelting is available for ballast, but it must first be sized in a screening plant at the slag dump near the smelter.

Improved track has made possible utilization of the rapid acceleration characteristics of the diesel-electric locomotives, and train speeds have increased generally; as a result overall mining efficiences have increased. Furthermore, improved track conditions have resulted in fewer derailments and other delays to train movements. Table 6 compares the efficiencies of non-supervisory maintenance-of-way employees for three periods. The first period of improvement has been attributed to the adoption of panel track; the second period results from the mechanization of track-maintenance procedures.

TABLE 6. - Track efficiencies compared

Year	Rail-tons per day	Miles of track	Number of track employees	Employees per mile
1942.....	69,140	35.0	290	8.3
1947.....	103,027	48.5	190	3.9
1956.....	141,554	68.0	140	2.0

Truck Haulage

The Morenci mine is equipped with 14 off-highway trucks of 29 tons capacity and 4 off-highway trucks of 45 tons capacity. These are called 25- and 35-ton trucks, respectively. The 25-ton trucks are single-axle, dual-wheel, rear-dump type and are powered with 300-hp., eight-cylinder, supercharged diesel engines. Power is transmitted to the wheels with a three-stage torque converter and a planetary drive axle. Hydraulic booster steering is provided. Two hydraulic, three-stage, double-acting, telescoping cylinders dump the load. Figure 37 shows the dimensions of the 25-ton truck. The 35-ton trucks also have single rear axles and are similar in construction to the 25-ton trucks. All components are designed for the heavier load; this truck uses a 400-hp., 12-cylinder diesel engine that is not supercharged.

Trucks are used to prepare preliminary grades for railroad tracks or in areas where the quantity of material does not justify the preparation necessary for track haulage. (See fig. 38.) They are used to establish new levels where drop cuts are involved as the pit progresses in depth.

Usually 12 of the 18 trucks are operated on a shift; however, the number depends on the length of haul, condition of the road, and even the weather. The 25-ton trucks haul an average of 29 tons per trip, or about 900 tons per shift where the average length of haul is 3,000 feet; they consume about 40 gallons of fuel per shift. Tires for the 25-ton trucks last about 7,500 miles. The 35-ton trucks average 45 tons per trip, or about 1,100 tons per shift where the average length of haul is 3,000 feet. The tonnage per shift varies directly with the length of haul; at times, the average length of haul has been 7,000 feet.

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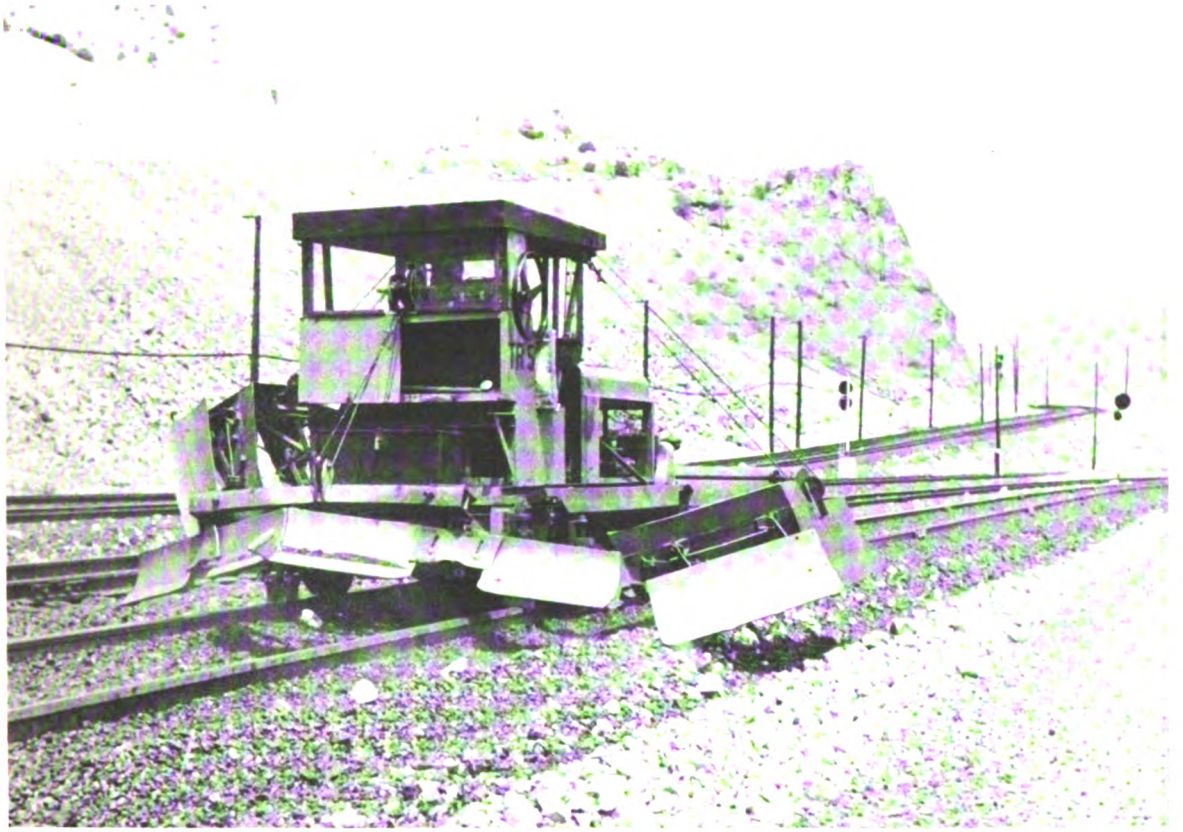

FIGURE 35. - Track Ballast-Spreading Car.

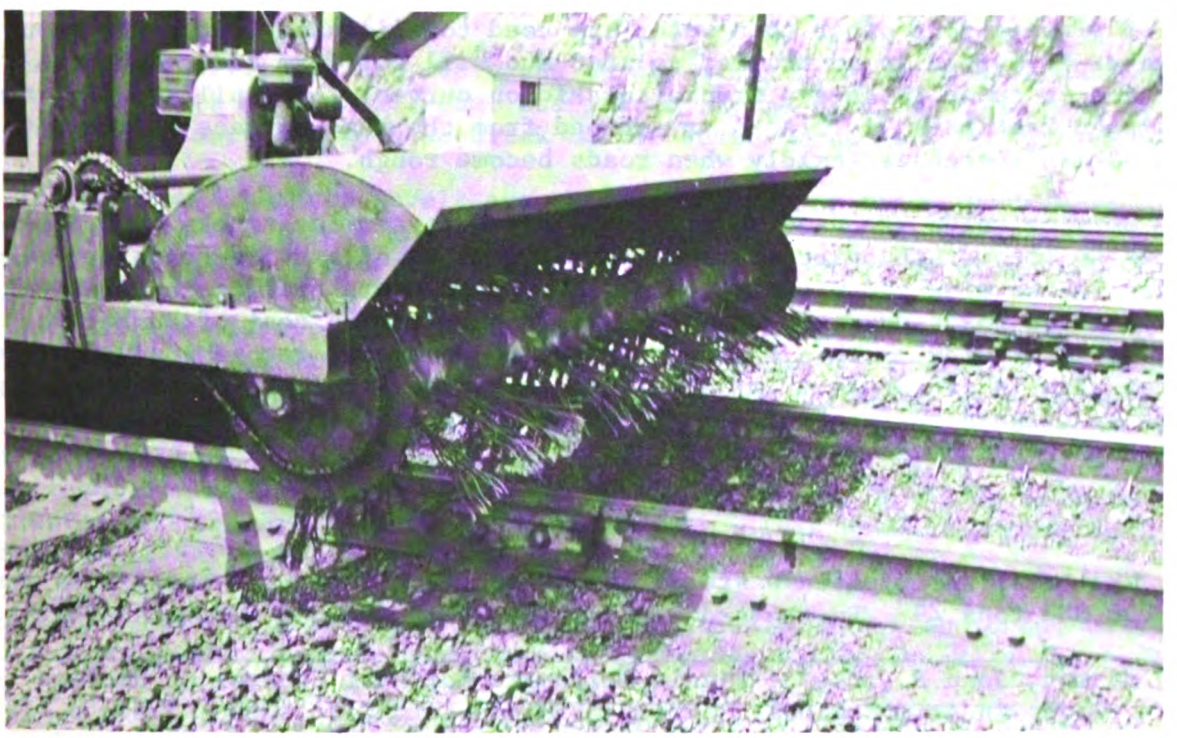

FIGURE 36. - Broom Mounted on Rear of Ballast-Spreading Car.

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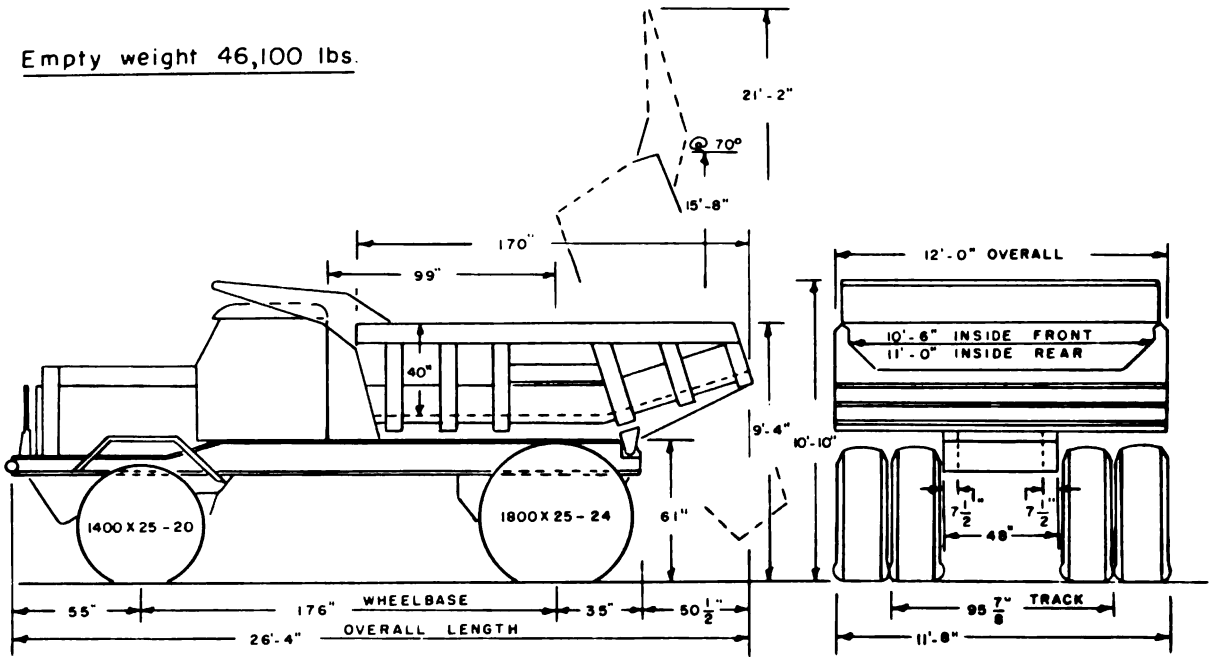

FIGURE 37. - Dimensions of 16-Cubic-Yard (25-Ton) Truck.

There is a difference in the treatment of haulage roads and service roads. Haulage roads are used by heavy trucks that haul ore or waste and extend from shovel to disposal point. They are bladed smooth and sprinkled with water, and no preparations other than water are used to eliminate dust. The amount of water is carefully controlled so that mud will not form and reduce the traction or cause the heavy trucks to skid on curves. Any spillage from trucks or slough from banks is bladed or scraped from the road surface to prevent tire wear, which increases rapidly when roads become rough.

Service roads are used to provide equipment, service trucks, and personnel access to the working places. More than 100 miles of service roads are maintained in the mine and vicinity. In waste areas where traffic is relatively heavy, these roads are treated with a light penetration coat of Bunker No. 7 oil. (See fig. 39.) This oil affects the concentrator recovery adversely and is not used in ore areas. In these areas a byproduct of the paper-processing industry (lignin sulfonate)23/ is used, or where traffic is light the road is sprinkled occasionally with water.

Waste Dumps

The total anticipated waste at the beginning of open-pit operations was 230,000,000 tons.24/ By the end of September 1956, 405,000,000 tons of waste

23/ Harmon, John P., Use of Lignin Sulfonate for Dust Control on Haulage Roads in Arid Regions: Bureau of Mines Inf. Circ. 7806, 1957, p. 12.

24/ Lawson, Walter C., Development and Operation of the Mine, Morenci Issue: Min. and Met., vol. 23, No. 425, May 1942, p. 250.

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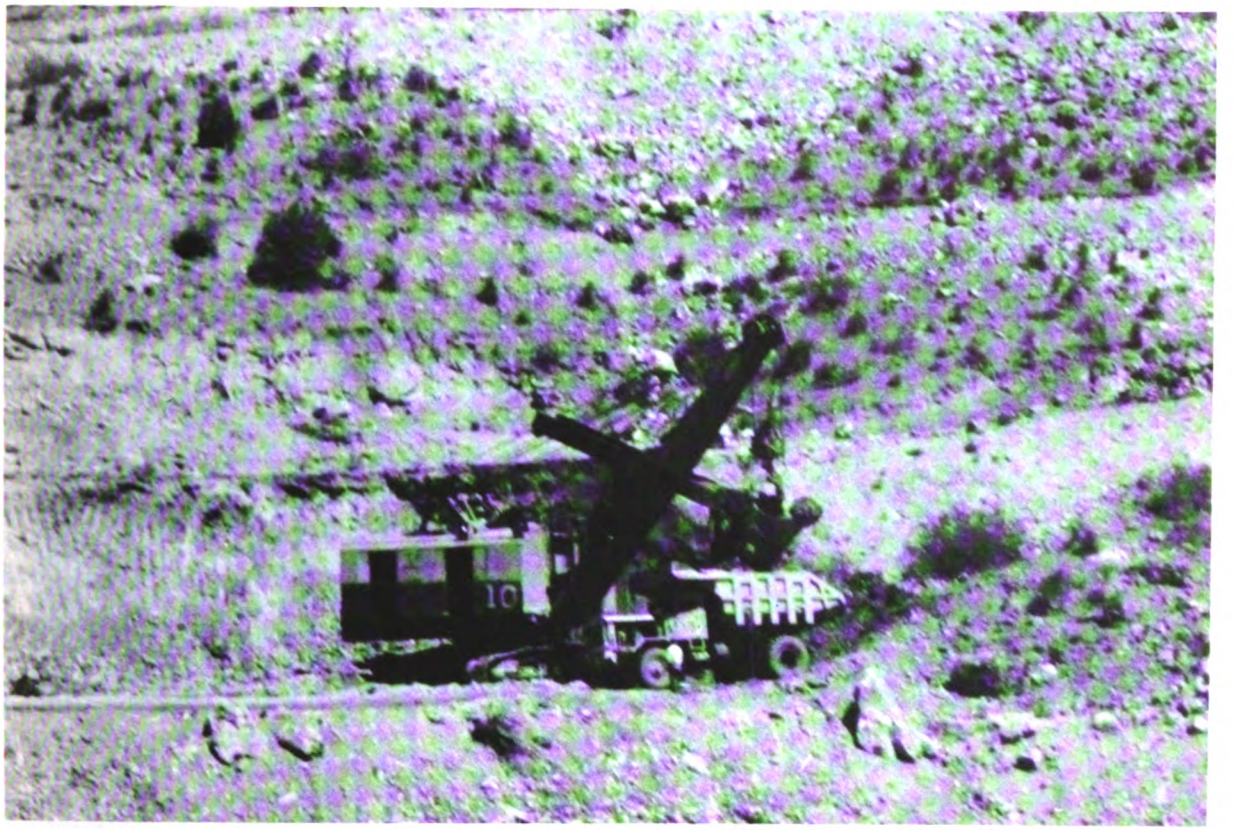

FIGURE 38. - Shovel Loading a 25-Ton Truck at Start of New Level Development.

had been mined. Part of this waste was dumped along Coronado Canyon and Fairbanks Canyon north of the pit, some was placed on the Producer dump, and the remainder was dumped along Chase Creek Canyon between the mine and the crusher.

Tracks from alternate levels are extended north for the upper levels. Each dump serves two levels and is connected to the alternate level by a 3-1/2-percent grade. Dumps are carried at approximately 100-foot vertical intervals.

As lower levels were opened additional waste-disposal area was needed, and in 1956 a project was under way to develop and use the Stargo Canyon area southwest of the crusher. To reach this area it was necessary to cross Morenci Canyon. Through this canyon runs the section of single track from Clifton to Morenci, over which all mine-bound railroad freight is hauled. To reach the area without interrupting traffic, a prefabricated tunnel 324 feet long was constructed and the waste dumped over the tunnel. This notable engineering accomplishment has been described by Orr.25/

Waste is dumped from cars on a track along the crest of the dump. When no more waste can be dumped, the track is cut and a bulldozer pulls the track

25/ Orr, David H., Jr., Traffic Shutdowns Averted by "Synthetic" Tunnel at Morenci: Eng. Min. Jour., vol. 157, No. 1, January 1956, pp. 85-87.

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FIGURE 39. - Light Oil Surface on Service Roads.

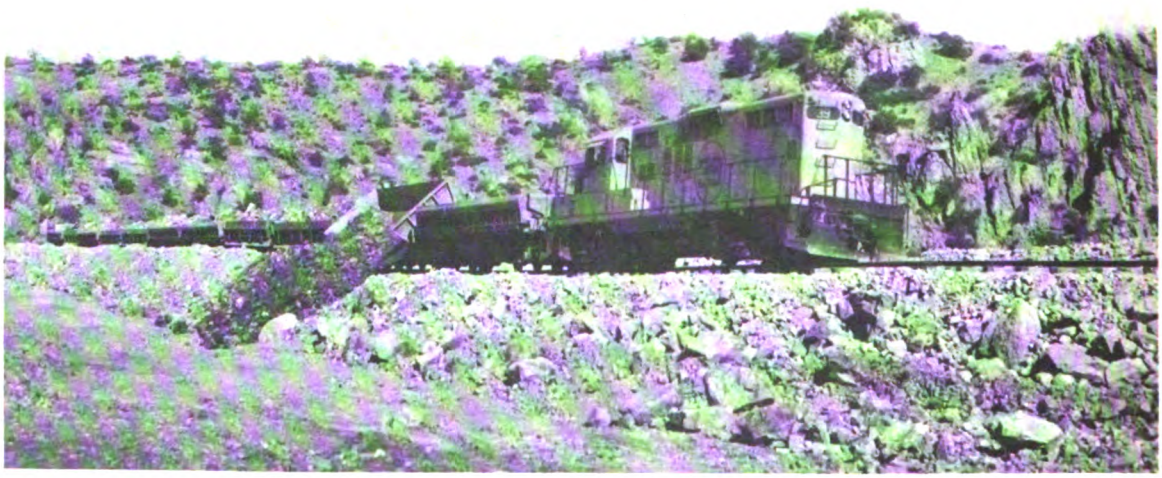

FIGURE 40. - Train on Waste Dump.

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from the crest of the dump. The bulldozer then prepares a new grade for the track along the outside edge of the dump, and the track is shifted with a track shifter or pushed with a dozer to the new grade; then the cycle is repeated. The track move is 8 to 15 feet.

After several months the crests of high dumps tend to settle and low spots develop in the track. When the movement reaches the extent (15 to 20 feet) that train operating efficiency is decreased, the track is moved back from the crest to a level position and rock is dumped over the top of the previous dump. (See fig. 40). Usually, after the area is covered the second time the dumps do not settle.

Engineering Control

Engineering service is required for estimating tonnage, horizontal and vertical control of digging grades, and ore control or separating ore and waste.

Tonnage calculations are made every 3 months by a method devised at Morenci called the plan-section method. The usual method of determining volume and tonnage is by plotting vertical cross sections from a topographic map at uniform intervals across the area. At Morenci, tonnage is calculated directly from plan level maps, eliminating the necessity of preparing vertical cross sections. Tonnage calculations take only about 25 percent of the man-hours that were formerly required.

Horizontal control is established by triangulation, or by traverse from triangulation points. Stations are systematically established in the working area so that, when pit progress is shot by stadia survey, the shots are short (less than 500 feet) and vertical angles are unnecessary. Office calculations to locate survey stations are made uniform by the use of standard forms (figs. 41 and 42). Vertical control is established by direct levels.

The term "ore control" is applied to the sampling and marking of broken material in the mine so that the operating department will know whether to send it to the crusher or dumps. This function is supervised by the ore-control engineer. All drill holes are sampled. The holes are located in the field and plotted on a map to a scale of 100 feet to the inch. When the assay returns for the drill-hole samples are received, the copper content is recorded adjacent to the plotted position of the drill hole on the map.

When the drill-hole assay indicates a change from ore to waste or waste to ore, a straight line is drawn on the map normal to the bank and track at the point of change. The ore-control engineer measures on the map from the intersection of this line with the track to the nearest marked survey station and places a target in the field at the same relative position.

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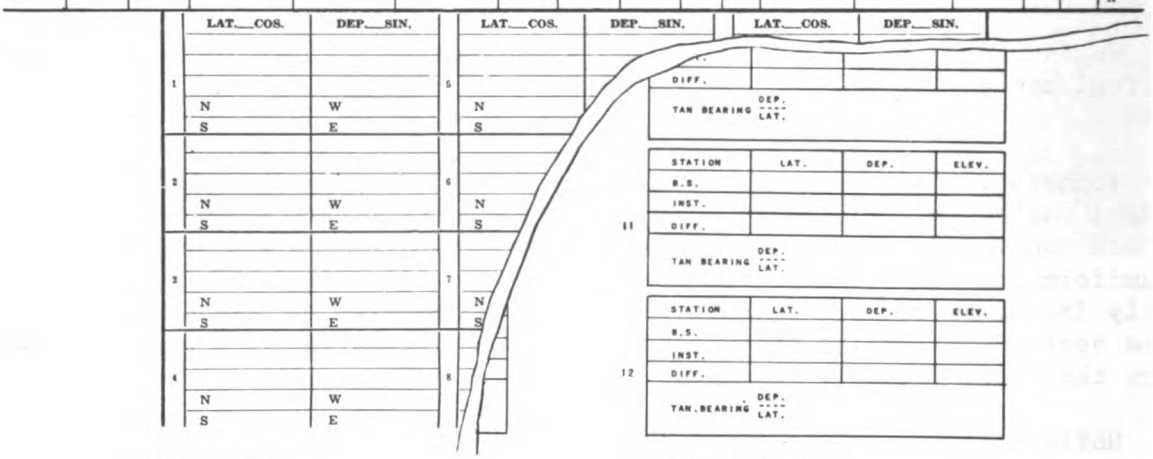
PHELPS DODGE CORPORATION—*Morenci Branch*

CHAIN TRAVERSE

B. S.	Inst.	F. S.	Hor. Angle	Azimuth	Course	Hor. Dist.	Vertical Angle	Slope Dist.	H. I.	Vert Dist.	CO-ORDINATES LAT.	CO-ORDINATES DEP.	Elevation	Engr.	Ch'k'd By	No.
																1
																2
																3
																4
																5
																6
																7
																8
																9
																10
																11
																12



FORM NO. 6

(REVERSE SIDE)

FIGURE 41. - Chain Traverse–Guide for Calculations.

Operating Control

Operating control at the Morenci mine is accomplished through verbal orders, and results are recorded on reports. Truck roads suitable for travel by light pickup trucks permit access to all parts of the mine. Each department foreman is provided with a pickup that is equipped with a sending-receiving radio set. With this equipment a foreman is able to supervise efficiently men distributed over a wide area and contact higher officials for instructions or other departments for supplies or mechanical assistance.

All train movements in the mine are controlled with a block-signal system by a chief dispatcher who can see most of the activity from a lookout tower high on the south edge. In addition, certain locomotives are equipped with a two-way radio set, and the operator can be contacted for specific instructions.

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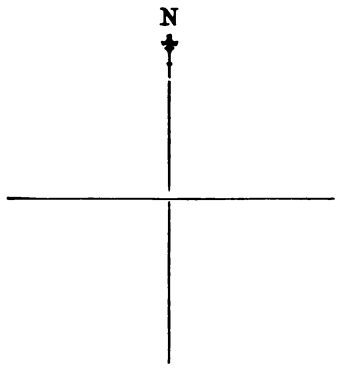

TRIANGULATION STATION

NO. ————————

ELEVATION ————————

STA. LAT. DEP.

TAN. BEARING $c = \frac{\text{DEP.}}{\text{LAT.}} =$ =

INTERIOR ANGLES

A

B

C

180°

* c = =

$a = \frac{c \text{ SIN. A}}{\text{SIN. C}} =$ ———————— =

$b = \frac{c \text{ SIN. B}}{\text{SIN. C}} =$ ———————— =

LAT. a = a COS. BEARING a =

DEP. a = a SIN. BEARING a =

LAT. b = b COS. BEARING b =

DEP. b = b SIN. BEARING b =

STATION NO. ————		STATION NO. ————	
LAT.	DEP.	LAT.	DEP.
————————	————————	————————	————————

ACCEPTED CO-ORDINATES { LAT. ———————— DEP.

TRIANGULATED BY ————————

COMPUTED BY ————————

DATE ————————

*c WILL BE KNOWN SIDE OF TRIANGLE

FORM NO. 7

FIGURE 42. - Triangulation Station–Guide for Calculations.

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PHELPS DODGE CORPORATION
Morenci Branch
DAILY SHOVEL REPORT

Shovel No. ..... Shift ..... Level ..... Date .....

TRUCKS							DELAYS				EXPLANATION OF DELAYS
Time Start and End Shift			Loading Time	Trucks Loaded 220 Yards	Trucks Loaded 6 Yards	Ore or Waste	Drilling and Blasting	Mechanical	Electrical	Truck Service	Over 5 minutes—give detail. Less than 5 minutes—charge to loading time.

Condition at end of shift: Pit ..... Shovel ..... Power Cable .....

Pitman .....
Oiler .....
Runner .....

Moved to Shovel No. ..... at ..... M. Acct.

FIGURE 43. - Daily Shovel Report—Trucks (Form 8).

PHELPS DODGE CORPORATION
Morenci Branch
DAILY SHOVEL REPORT

Shovel No. ..... Shift ..... Level ..... Date .....

TRAINS							DELAYS				EXPLANATION OF DELAYS
Locomotive Number	Arrival at Shovel	Leaving Shovel	Loading Time	Cars Loaded 30 Yard	Cars Loaded 40 Yard	Ore or Waste	Drilling and Blasting	Mechanical	Electrical	Train Service	Over 5 minutes—give detail. Less than 5 minutes—charge to loading time.

Condition at end of shift: Pit ..... Shovel ..... Power Cable .....

Pitman .....
Oiler .....
Runner .....

Moved to Shovel No. ..... at ..... M. Acct.

FIGURE 44. - Daily Shovel Report—Trains (Form 9).

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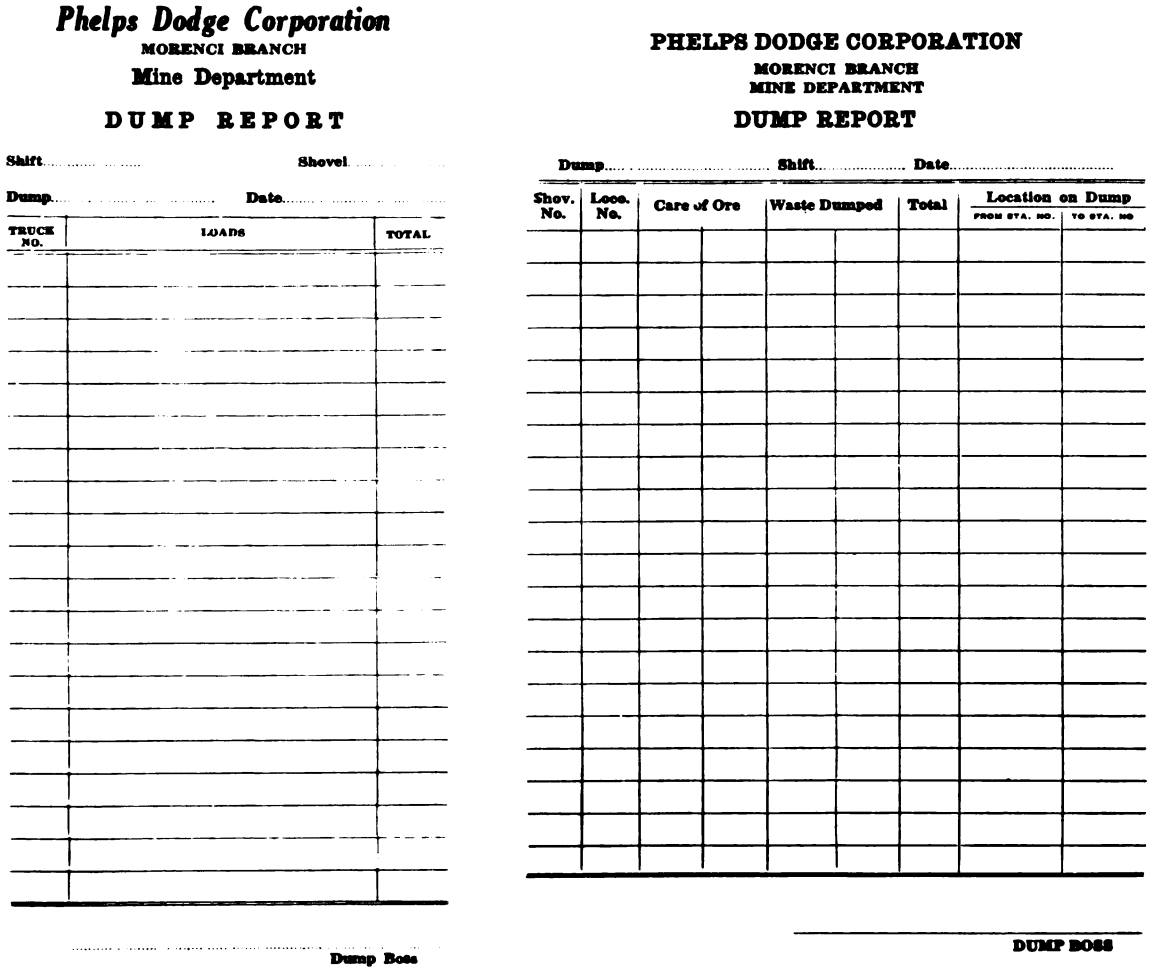
Forms and Reports

A production report is made by the operator for each piece of major equipment. The report shows production of the unit for an 8-hour shift. Shovel reports (figs. 43 and 44) show the number of cars of ore or waste loaded. Dump reports (fig. 45, forms 10 and 11) show where waste was dumped. A crusher report indicates how many cars of ore were received. Information from these reports is posted to the pit production report and to the report of mining operations (fig. 46), which is the final report by the mine superintendent to the manager for the day's operation. Haulage efficiencies are reported on a daily truck report and a daily locomotive report (fig. 47).



Phelps Dodge Corporation
MORENCI BRANCH
Mine Department

DUMP REPORT

Shift..... Shovel.....

Dump..... Date.....

TRUCK NO.	LOADS	TOTAL

Dump Boss

PHELPS DODGE CORPORATION
MORENCI BRANCH
MINE DEPARTMENT

DUMP REPORT

Dump..... Shift..... Date.....

Shov. No.	Loco. No.	Cars of Ore		Waste Dumped		Total	Location on Dump	
							FROM STA. NO.	TO STA. NO

DUMP BOSS

FIGURE 45. - Dump Report—Trucks and Trains (Forms 10 and 11).

A churn-drill daily lineup (fig. 48) is made by the drilling foreman for each shift. Each drill crew completes a daily churn-drill report (fig. 49) at the end of the shift. The foreman of the new shift checks the supplies-needed section of the drill report for the last shift and makes a check list of

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PHELPS DODGE CORPORATION

MORENCI BRANCH—MORENCI OPEN PIT MINE

REPORT OF MINING OPERATIONS

Date.....

Shovel Number	Bench	TONS PRODUCED TODAY				Shovel Number	TONS PRODUCED THIS MONTH TO DATE				Total Tons Last Month
			Ore to Mill	Leach	Waste	Total			Ore to Mill	Leach	Waste	Total	
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
10							10						
11							11						
12							12						
13							13						
14							14						
15							15						
16							16						
17							17						
18							18						
19							19						
Total							T						
A Shift							A						
B Shift							B						
C Shift							C						

Shovel Number	Shifts Worked	TONS PER SHOVEL SHIFT—TODAY					Shifts Worked	TONS PER SHOVEL SHIFT—MONTH TO DATE					Tons Per Shovel Shift Last Month
			Ore to Mill	Leach	Waste	Total			Ore to Mill	Leach	Waste	Total	
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
Total													
A Shift													
B Shift													
C Shift													

	Today	Yesterday	To Date	Last Month
Man Shifts—Total—Trucks and Trains				
Tons Mined per Man-Shift—Total—Based on Total Tonnage				
Grade of Ore Milled—% cu.				
Shovels Delayed Waiting for Trucks or Trains—Minutes				
Shovels Delayed Waiting for Trucks or Trains—%				
Number of Days Operated				
Maximum Tons Loaded in Single Shift				
Ore Milled—Wet Tons				
Trucks Loaded—Ore—5 Yd.—25 Ton				
Trucks Loaded—Leach—5 Yd.—25 Ton				
Trucks Loaded—Waste—5 Yd.—25 Ton				
Train Cars Loaded—Ore—40 Yd.				
Train Cars Loaded—Leach—40 Yd.				
Train Cars Loaded—Waste—40 Yd.				
Total Tonnage—Trucks and Trains				
Total Tonnage—Waste Ratio				
Tons per Shovel Shift—Trucks and Trains				
Truck Factor—Tons Per 5 Yd. Truck				
Truck Factor—Tons Per 25 Ton Truck				
TRAIN CAR FACTOR—Tons Per 40 Yd. and 43 Yd.				

TOTAL DELAYS

Shift	Shovel	Travel Time	Lunch and Greasing	Truck or Train Del.	Blasting	Power Off	Moving	Misc.	Repairs	Description
A										
B										
C										

FIGURE 46. - Report of Mining Operations (Form 12).

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PHELPS DODGE CORPORATION
Morenci Branch
MINE DEPARTMENT
DAILY LOCOMOTIVE REPORT

Locomotive..... Date ..... Shift..... Car Nos.....

Hauling							Ore			Waste			Time Consumed—Mins.							Delay Time—Mins.											
Trip No.	Shovel No.	Arrival at Shovel	Leaving Shovel	30-Yd. Cars Loaded	40-Yd. Cars Loaded	Ore or Waste	Crusher No.	Arrival on Crusher	Leaving Crusher	Dump No.	Arrival on Dump	Leaving Dump	Loading	To Crusher	Dumping	To Shovel	To Dump	Dumping	To Shovel	Starting Up	Taking Fuel Oil	Taking Water	Diesel Repairs	Electric Repairs	Switching	Waiting With Loads	Waiting With Empties	On Spot At Crusher Sw.	On Spot At Dump Sw.	On Spot At Shovel
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
9																														
10																														
11																														

REMARKS

Fuel Oil Record

Lubricating Oil

Engineer

Brakeman

All delay time under 5 minutes to be charged to operation.

FIGURE 47. - Daily Locomotive Report (Form 13).

miscellaneous supplies needed. A regular form is prepared for this list (fig. 50). The daily churn-drill reports are sent to a clerk in the drilling and blasting office, who extracts information to complete a churn-drill-operations report (fig. 51). This is the final report by the drilling and blasting foreman to the mine superintendent on churn-drill operation. Air-drill footage is reported to the foreman by each machine crew and compiled by the foreman on form 18 (fig. 52). Figures 53, 54, and 55 show how activities of the drill-sharpening shop are recorded.

Powder is issued by the magazine keeper to a powder truck only when an order (fig. 56) has been signed by the loading foreman. The amount and types of explosives that have been issued are recorded (fig. 57), and a daily report called explosives issued and inventory to date (fig. 58) is prepared and sent to the drilling and blasting foreman.

Many other forms, besides those shown, are used to account properly for production and to evaluate the performance of production equipment. Those illustrated in this report are typical.

PERCENTAGE OF EXTRACTION AND PRODUCTION RATE

In the area of the ore body that is mined by the open-pit method, virtually 100 percent of the ore is extracted. Only an insignificant amount is lost that is unavoidably mixed with waste during mining and sent to the dumps.

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CHURN DRILL DAILY LINE UP

Date _____ Shift _____

Level	C. D. No.	Work	B.O.
5400			
5350			
5300			
5250			
5200			
5150			
5100			
5050			
5000			
4950			
4900			
4850			
4800			
4750			
4700			
4650			
4600			
4550			
4500			
4450			
4400			
4350			
4300			
Bulldozer			

FIGURE 48. - Churn-Drill Daily Lineup (Form 14).

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PHELPS DODGE CORPORATION

MORENCI OPEN PIT

DAILY CHURN DRILL REPORT

Drill No. ..... Shift ..... Level ..... Date ..... 19 ...

Relieved Driller ____ Helper ____ Time ____

Condition of drill at start of shift ____

Condition of drill at end of shift ____

Relieved by Driller ____ Helper ____ Time ____

Hole Number				
Total Depth				
Started Drilling				
From—Depth				
Drilled to—Depth				
Footage Drilled				
Finished Hole—Time				
Formation—Hardness				
Drilling Time				
Moving Time				
Dead Time and Explanation				
Total Time				

SUPPLIES	AMOUNT NEEDED
Bits	
Casing	
Crosses	
Jack Blocks	
Jack Bars	
Lubricants	
Water Hose	
Report Sheets	
Power Cable	
Bit Wrenches	
Cribbing	
Miscellaneous	

BIT CHANGES			
Hole No.	Depth	Dull Bit	Sharp Bit

CONDITION OF EQUIPMENT AND SUPPLIES	
Sharp Bits	Dull Bits
Good Casing	B. O. Casing
Holes Staked Ahead	
Metal Stakes on Machine	
Safety Belt	
Cable Cutter	
Grease Gun	

REMARKS:

Driller .....

Helper .....

FIGURE 49. - Daily Churn-Drill Report (Form 15).

At Morenci considerable material that contains copper in the form of carbonate and silicate minerals is mined. This material has been segregated from the general waste and stored in a separate area.

The Morenci mine is currently being operated to produce 52,000 tons of sulfide ore per 24-hour day. In addition, 118,000 tons of waste and leach material is mined.

MINE DRAINAGE

Provision for mine drainage has been unnecessary in the past, as the east end of the pit is open. Several levels are contemplated below the present bottom. It will then be necessary to pump from those levels, but the quantity of water is expected to be small except during heavy rainstorms.

FIRE PREVENTION

Fire hydrants are provided near principal buildings and in the townsite. Traveling units, such as trucks, electric shovels, and locomotives, are

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Date _____

MISCELLANEOUS SUPPLIES NEEDED

Level C D Number	Condition	Sharp Bits	Casings	Power cable	Crosses	Jack Blocks	Cribbing	Jack Bars	Water Hose	Lubricants	Report Sheets	Bit Wrenches	Safety Belts	Cable Tongs	Holes Staked	Miscellaneous	Remarks
5400																	
5350																	
5300																	
5250																	
5200																	
5150																	
5100																	
5050																	
5000																	
4950																	
4900																	
4850																	
4800																	
4750																	
4700																	
4650																	
4600																	
4550																	
4500																	
4450																	
4400																	
4350																	
4300																	

Remarks: _____

Bulldozer: _____

FIGURE 50. - Miscellaneous-Supplies-Needed Report (Form 16).

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PHELPS DODGE CORPORATION—*Morenci Branch*

MINE DEPARTMENT

CHURN DRILL OPERATIONS

Division: **Date:**

	Level		Operator	Shifts	Feet	Bits Used	Time Drilling	Mins. Delays	MONTH TO DATE Shifts	Feet	Ft. Per Shift
FEET DRILLED TODAY											
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
		A									
		B									
		C									
			TOTAL								
			A Shift								
			B Shift								
			C Shift								

DELAYS

Shift	Oiling	T.T.	Mech.	Elec.	Bistg.	C. Holes	Misc.	Description	Total
A									
B									
C									
Total									
To Date									

Per Cent _____ %

FIGURE 51. - Churn-Drill-Operations Report (Form 17).

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PHELPS DODGE CORPORATION
MORENCI BRANCH
DAILY AIR DRILL REPORT

SHIFT DATE DRILL FOREMAN

No. Men	Drill Crews	Mach.	Bank	Formation	Cond. Mach.	Drilling Time	Delays—Time and Explanation	Number Holes Drilled	Depth Holes	Total Footage

FIGURE 52. - Daily Air-Drill Report (Form 18).

equipped with fire extinguishers. A volunteer fire-fighting crew is trained and reports on signal to the location of a fire in the townsite. Equipment is furnished by the company.

SAFETY AND FIRST-AID ORGANIZATION AND TRAINING

A safety engineer and three assistants supervise a well-organized safety program for the mine, mill, and smelter. New employees are instructed in safe working procedures and are taken on a guided trip through their job area; they are cautioned about unsafe practices.

Of particular importance in the Morenci safety program are the codes of safe practice that are used in training new employees. These codes are the result of a cooperative effort by operating and safety departments and are prepared by men who are thoroughly familiar with the work. They provide a set of safe operating rules for each job.

Each employee is given copies of the codes that pertain to his work and asked to read and study them. The supervisor discusses the code with the employee, and after a few weeks the employee may be examined by a questionnaire to determine if he has a clear understanding of the proper way to do his job

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PHELPS DODGE CORPORATION
Morenci Branch
DRILL SHARPENING SHOP DAILY REPORT

Division _____ Date _____

	"D" Bits	"H" Bits	C. B. Bits		Primary	Sec'dary
Bits Sent Out						
New						
Reground or Redressed						
Bits Returned						
Bits Discarded						
Bits Reground or Dressed						
Bits Hardened or Tempered						
Bits Annealed						
Hours Grinding or Dressing						
Hours Hardening or Tempering						
Hours Annealing						
Hours Steel Convention						
Hours Miscellaneous Labor						

Remarks:

_____
Drill Shop Foreman

FIGURE 53. - Drill-Sharpening-Shop Daily Report (Form 19).

PHELPS DODGE CORPORATION
MORENCI BRANCH
DRILL SHOP TIMKEN BIT REPORT

Date _____

BITS REGROUND		HRS. GRINDING		BITS HARDENED		HRS. HARDENING		BITS ANNEALED		HRS. ANNEALING	
D	H	D	H	D	H	D	H	D	H	D	H

Bits Sent Out

BITS REGROUND		LOCATION	NEW BITS		LOCATION	DISCARDS		
D	H		D	H		D	H	

Bits Returned

D	H	LOCATION	D	H	LOCATION			

REMARKS:

FIGURE 54. - Drill-Shop Timken-Bit Report (Form 20).

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PHELPS DODGE CORPORATION
MORENCI BRANCH

DAILY CHURN DRILL BIT REPORT

Date **Shift**

SHOW NUMBER OF BITS DRESSED

Bits Sent Out	Location	Bits Returned	Location

Bits Dressed	Bits Tempered	Hours Dressing	Hours Tempering
1			
2			
3			

Shop Foreman

REMARKS:

FIGURE 55. - Daily Churn-Drill Bit Report (Form 21).

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PHELPS DODGE CORPORATION—Morenci Branch

To Magazine Keeper:
Please issue following explosives to bearer, ... **Date** .....

POWDER			Charge Number	Location of Blast
Kind	Size	Quantity		
Dynamite LDx 705 70%	Bags			
	Bags			
	Bags			
	Bags			
	Bags			
Amogel				
Spl. Gel. 40%	⅞ x 8			
40%	1¼ x 12			
40%	8 x 18			
40%	4 x 8			
60%	8 x 18			
Tacos				
Tamp. Sticks	1-1 ⅛" x 24'			
Primacord	1000' Cs.			

8X Inst. Elec. Caps	Lgth.	Qnty.	Chg. No.	Loc'n.
	8'			
	12'			
	16'			
	20'			
	24'			
	30'			
	36'			
	80'			

..... **Signed**

FIGURE 56. - Request for Powder (Form 22).

safely. These codes give new men, experienced workmen, and supervisors a clear definition of the details of working safely.

Codes of safe practice, rulebooks, and safety pamphlets are used to assist in a continuous program to improve the safety record. In addition to the safety department, various safety committees, safety training, statistical analyses, and wholehearted support for protective measures are provided by the company. Safety signs are posted in prominent places, and

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PHELPS DODGE CORPORATION--- *Morenci Branch*

Explosives Issued To _____ **Period For Month** _____ **19 —**

DATE	Quarry Dynamite		Special Gelatin				Quarry Gelatin			TOTAL BOXES	PRIMACORD		Sequoia Fuse Feet	W.E. Big Inch Caps	6X Inst. Elec. Caps				Tamp. Sticks 24'		Mag. Temp.
	LDX 705-70%		40% 7/8x8	60% 11/4x12	60% 4x8		60% 4-Bag	60% 8x18			Reg. Cases	Feet			16 Feet	40 Feet	Feet	TOTAL INST. CAPS			

FIGURE 57. - Explosives-Issued Record (Form 23).

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Date _____

EXPLOSIVES ISSUED AND INVENTORY
TO DATE

Issued to Date		Inventory to Date	
Total Issued All Charge Nos.	Boxes		Boxes
QUARRY DYNAMITE		QUARRY DYNAMITE	
LDX 705 - 70%		LDX 705 - 70%	
Carbomite - 50# Bags		Carbomite - 50# Bags	
SPECIAL GELATIN		SPECIAL GELATIN	
40% 7/8 x 8		40% 7/8 x 8	
60% 1¼ x 12		60% 1¼ x 12	
60% 4 x 8		60% 4 x 8	
QUARRY GELATIN		QUARRY GELATIN	
60% 4-Bag Quarry		60% 4-Bag Quarry	
60% 8 x 18 Quarry		60% 8 x 18 Quarry	
Total Issued to M.O.P.		TOTAL	
			Quantity
		Primacord - 1000' Cases	
		Primacord Relays	
RECEIVED TODAY		W. E. Big Inch Caps	
		6X Western Blstg. Caps Big Inch	
		Sequoia Fuse - Lineal Feet	
		6X Instant. Electric Caps	
		Tamping Sticks 24'	
		Tamping Sticks 16'	

FIGURE 58. - Explosives Inventory (Form 24).

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such visual aids as slides, charts, and moving pictures are used in meetings to advance the safety program. Some information has been published.[26 27]

A well-equipped hospital is maintained by the corporation and staffed by competent doctors. All parts of the mine are accessible by road, and any point can be reached by ambulance in case of an accident. Regular inspections are made by the safety department.

WAGE, CONTRACT, LEASING, OR BONUS SYSTEMS

All employees are on a straight hourly wage. Supervisory personnel are on a salary. No contract, leasing, or bonus systems are used.

ORGANIZATION

The Morenci Branch, Phelps Dodge Corp., is ranked as the second largest copper-producing mine in the United States. The operating organization comprises the open pit, ore dressing, smelting, maintenance, and miscellaneous divisions, each headed by a superintendent who reports to the branch manager, as do the heads of the accounting, engineering, safety, medical, supply, and chemical departments.

Employment in the branch, including mine, concentrating, smelting, and other divisions, totals approximately 2,350 men. Less than 1,000 of these men are employed in the mine.

REDUCTION PLANT

The processing plant consists of a concentrator and a smelter. A complete description of these divisions is beyond the scope of this paper. Figure 59 is a flowsheet of the concentrator. Both the concentrator and the smelter have been described,[28] and additional information on the concentrator was published after it was enlarged.[29]

The Morenci ore is a medium-hard monzonite porphyry. The principal sulfide minerals are chalcocite and pyrite. The chalcocite occurs mainly as a coating on pyrite. Various oxidized copper minerals are present, particularly near old stope areas. Some oxidation occurs after the ore is broken and before it is delivered to the crushing plant. The gangue ranges from hard to soft, depending on the extent of alteration of the feldspar.

26/ Williams, M. L., and Look, A. D., Use of Visual Aids in the Morenci Branch Safety Program, Phelps Dodge Corp., Morenci, Ariz.: Bureau of Mines Inf. Circ. 7598, 1951, 6 pp.

27/ Rodriquez, E. R., and Look, A. D., Safety in Pneumatic Drilling and Related Blasting Operations, Opencut Mine, Morenci Branch, Phelps Dodge Corp., Morenci, Ariz.: Bureau of Mines Inf. Circ. 7742, 1956, 23 pp.

28/ Mining and Metallurgy, Phelps Dodge Morenci Issue: Vol. 23, No. 425, AIME, May 1942, pp. 243-300.

29/ Cody, B. H., Milling Practices at Concentrator of Morenci Reduction Works: Min. Technol., AIME, vol. 11, No. 4, July 1947, 26 pp.

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The steps in concentrating this ore are: Three-stage crushing to minus-3/4-inch feed, single-stage grinding, and two-stage rougher flotation, followed by single-stage cleaning flotation with a regrind of secondary rougher concentrates and cleaner tailing before recycling them to roughers.

Notable improvements in the concentrator have been the incorporation of a molybdenum-recovery unit, better classification during regrinding through the use of cyclone-type classifier units, increase in the grade of concentrate through better reagent combination, and improvement of tailings disposal.30/ Table 7 lists concentrating equipment shown in the flowsheet, figure 59.

Concentrate from the filter plant is stored in a bedding area. From there it is conveyed to charging bins over 650-ton reverberatory furnaces in the smelter and charged, without roasting, through the roof of the furnaces. Matte is tapped into clay-lined launders that lead to ladles in the converter aisle, then transferred to Pierce-Smith converters. From the converters the copper goes to tilting furnaces that serve an anode-casting machine. Anodes are shipped to the Phelps Dodge refinery at El Paso, Tex.

30/ Allen, P. F., Tailings disposal at the Morenci Concentrator: Min. Eng., vol. 8, No. 7, July 1956, pp. 680.

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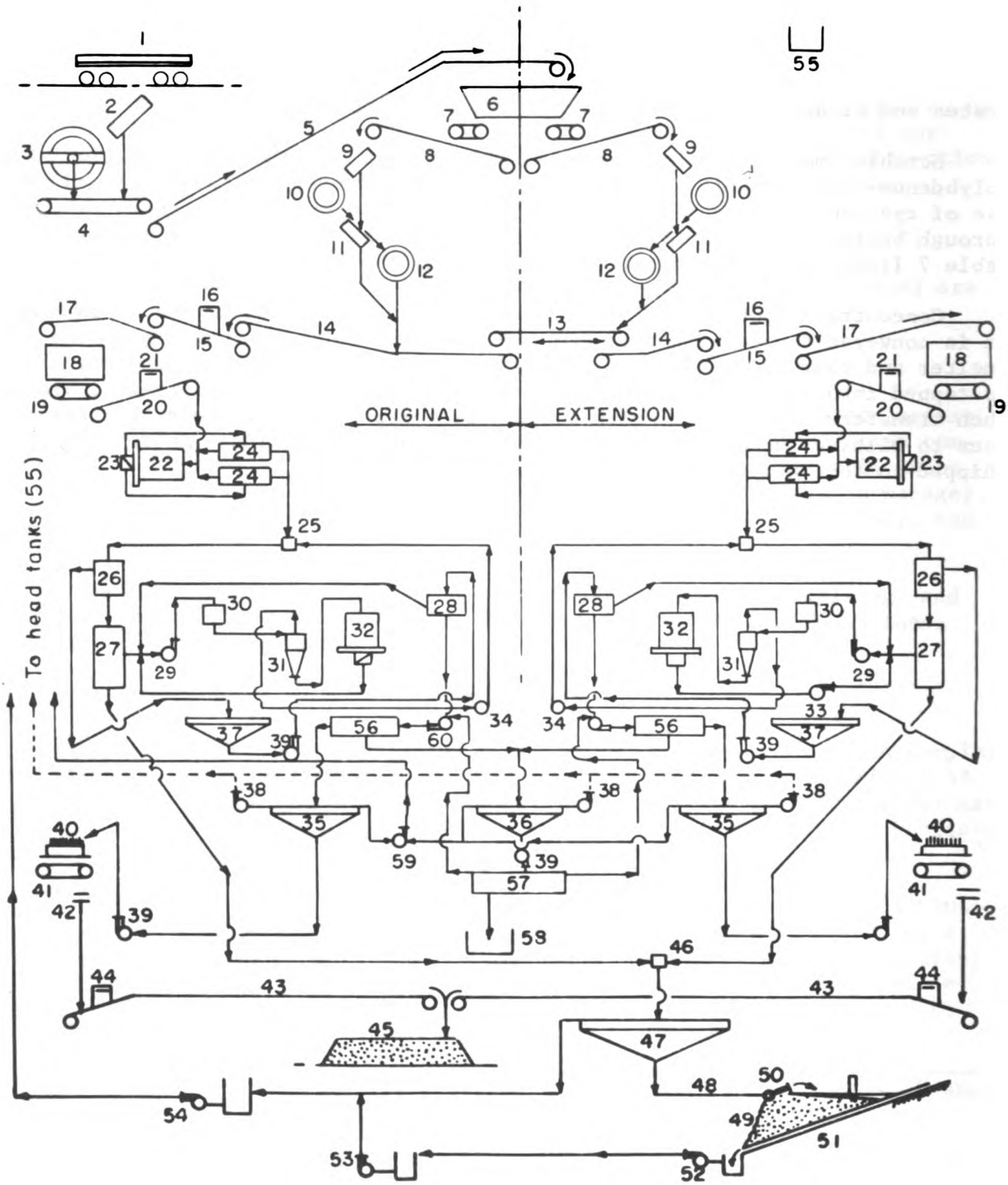

FIGURE 59. - Concentrator Flowsheet.

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LEGEND

CONCENTRATING EQUIPMENT

(Numbers Refer to Figure 59)

1 - 40 & 43 Cu. Yd. Ore Cars from Pit
2 - Manganese dressed grizzly, 6" openings, 40° inclination
3 - 60" Gyratory Crusher, 7" setting
4 - 2 Manganese Pan Feeders, 72" x 38'
5 - 2 54" Belt Conveyors, #1A & #1B
6 - Coarse Ore Storage Bins - 10,000 tons available Original, 10,000 tons Extension
7 - 16 Manganese Pan Feeders 48" x 13' - 8 Original, 8 Extension
8 - 4 60" Belt Conveyors - Nos. 2A and 2B Original, Nos. 2C and 2D Extension
9 - 4 6' x 11' Bar Grizzlies, 2" to 2-1/2" openings, 35° inclination - 2 Original, 2 Extension
10 - 4 Standard 7' Cone Crushers, 1-1/4" opening - 2 Original, 2 Extension
11 - 16 Rod Deck Screens, 7/16" opening, 3/8" rods, 25° inclination - 8 Original, 8 Extension
12 - 8 Shorthead 7' Cone Crushers, 3/8" setting - 4 Original, 4 Extension
13 - 1 54" Reversible Belt Conveyor - #3B Extension
14 - 2 54" Belt Conveyors - #3 Original, #3A Extension
15 - 2 54" Belt Conveyors - #4 Original, #4A Extension
16 - 2 Conveyor Scales
17 - 2 54" Belt Conveyors - #5 Original, #5A Extension
18 - Suspension Type Storage Bins - 16,000 tons cap. Original, 11,000 tons cap. Extension
19 - 27 36" Variable Speed Feeder Belts controlled by scales (No. 21) - 16 Orig., 11 Ext.
20 - 27 24" Belt Conveyors - 16 Original, 11 Extension
21 - 27 Conveyor Scales - 16 Original, 11 Extension
22 - 28 Grated Discharge Mills, 10' x 10', 17.9 R.P.M. - 16 Original, 12 Extension
23 - Helical Splitter Discharge from Ball Mills
24 - 56 Duplex 54" Submerged Spiral Classifiers, 5 R.P.M. - 32 Original, 24 Extension
25 - 4 Distributor and Mixing Boxes - 2 Original, 2 Extension
26 - Primary Rougher Flotation Machines, 66" Level Type - 80 Cells Orig., 64 Cells Extension
27 - Secondary Rougher Flotation Machines, 66" Level Type - 160 Original, 128 Extension
28 - Cleaner Flotation Machines, 56" Level Type - 24 Original, 20 Extension
29 - 3 8" Centrifugal Pumps - 2 Original, 1 Extension, (and 2 spares)
30 - 2 10' dia. x 18' High Tanks for Gravity Feed to Wet Cyclones - 1 Original, 1 Extension
31 - 5 Wet Cyclones - 3 Original, 30" diameter; 2 Extension, 20" diameter
32 - 5 Regrind Mills, 8-1/2' x 12', 18.1 R.P.M. - 3 Original, 2 Extension
33 - 2 3" Pumps on Extension only
34 - 4 8" Centrifugal Pumps - 2 Original, 2 Extension, with 1 spare O.P. and 2 spares Ext.
35 - 2 100' Concentrate Thickeners
36 - 1 100' Concentrate Thickener - Molybdenum Rougher Concentrate
37 - 3 100' Concentrate Thickeners - Dewatering Primary Rougher Concentrate (Cleaner Feed)
38 - 8 Pumps, 400 G.P.M. - Alternate route concentrate thickener overflow
39 - 3 Underflow Pumps (and 3 spares)
40 - 7 Filters, 7 Discs, 8-1/2' diameter - 4 Original, 3 Extension
41 - 7 30" Belt Conveyors - #8-1 to 8-4 Original, #8-6 to 8-8 Extension
42 - 2 30" Belt Conveyors - #9 Original, #9A Extension
43 - 2 20" Belt Conveyors - #10 Original, #10A Extension
44 - 2 Conveyor Scales - 1 Original, 1 Extension
45 - Smelter Bedding System - 3 Beds Original, 2 Beds Extension
46 - Tailing Distributor to Tailing Thickeners
47 - 7 Tailing Thickeners, Traction Type - 4-300' Original, 1-300' and 2-325' Extension
48 - 54" Concrete Launder Section, 17,600 Feet Long
49 - Tailing Storage Dams
50 - Tailing Dam Distributing Pipe
51 - Water Ducts and Connecting Chimneys
52 - Water Collecting System Pumps - 5 Original, 6 Extension - All 1000 G.P.M.
53 - Water Delivery Line Pumps - 5 Original, 3 Extension - All 1000 G.P.M.
54 - Reclaimed Water Main Pumps - 6 Pumps No. 4 Pump Station, 5 Pumps No. 5 Pump Station
55 - Head Tanks, 100,000 gallons each - 3 Original, 1 Extension
56 - Molybdenum Plant Roughers - 64 cells
57 - Molybdenum Plant
58 - Molybdenum Concentrate Storage Bins
59 - 2 5000 G.P.M. Pumps for Concentrate Thickener Overflow
60 - 4 8" Centrifugal Pumps - 2 Original, 2 Extension

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